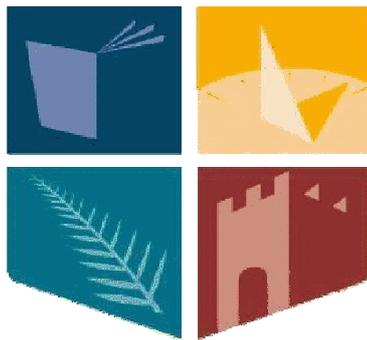


Software for the Control and Analysis of Public Transport  
Systems

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A THESIS SUBMITTED FOR THE QUALIFICATION  
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## DECLARATION

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# ABSTRACT

Public transport systems play an important role in providing mobility, combating traffic congestion, reducing carbon emissions, and improving economics. However, until recently, public transport systems have not exploited the full potential of information technology to improve their services and keep passengers informed of current service information. In order to convince people to leave their car at home and use public transport systems, a number of ways has been suggested, including reducing fares, introducing quality bus corridors and improving the public transport services reliability. However, the most effective strategy to achieve this is by improvements through the dissemination of up-to-date pertinent information and the reduction of perceived unreliability.

The research described in this thesis presents a methodology for developing a cost-effective public transport software system which can improve transit services and provide potential passengers with real-time transit information in an easy to understand and accessible way. The system also provides the transit operator with tools for monitoring, analysing and measuring their service. In order to reduce the cost of the communications and tracking infrastructure, the system uses a vehicle location system based on GPS/GPRS positioning technology that significantly reduces the cost of implementing real-time public transport tracking.

A number of features, including tools in the area of transit data visualisation, bus arrival time estimation, Quality of Service index calculation, delivering transit data on mobile devices and real-time navigation using the transport system are implemented. A test system was evaluated on a working bus route in a large town. The system demonstrates that sophisticated analysis and monitoring tools can be implemented cost-effectively. It is intended that by providing real-time passenger information, vehicle and route monitoring for transit operators and off-line analysis and measurement of transport system performance the public transport system will have a resurgence of use. It would also reduce route congestion, fuel consumption and carbon emissions.

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# **Chapter 1 Introduction**

## ***1.1 Introduction***

In developed countries, most people use private vehicles, and the level of vehicle ownership is rising rapidly, resulting in increased traffic congestion, which poses a threat to the overall quality of life of people in many countries. Traffic congestion also leads to a decrease in accessibility, excessive travel time and air pollution. A variety of techniques for reducing congestion has already been suggested (Glen, W., 2008). One suggestion is to improve and expand the public transport system. However, the growth in populations, the need to facilitate mobility, environmental concerns and energy objectives place demands on public transport systems. These systems must be constantly upgraded, improved and expanded to meet these demands.

Improving public transportation systems does not necessarily mean building new roads or repairing infrastructure. Instead, using new computer software and hardware techniques as well as communication networks can help in improving existing transport systems by providing real-time transit information to the public when and where they need it. Many people using public transit in their daily life face problems such as waiting for a long time at bus stops without knowing when the next bus will arrive or without getting enough information about the buses arriving at or leaving from bus stations. This is because buses are not tracked when they are on route. This has caused huge inconveniences to passengers who travel by bus.

Transit operators need tools to track their bus fleet in real-time and be able to monitor schedule adherence and service efficiency. By tracking their bus fleet in real-time, operators can give better operational support and provide users with real-time service information.

## ***1.2 Public Transport Systems***

Public transport has many synonyms, such as transit, public transit and mass transit. There are many definitions of public transport, but it includes all modes available to the public, irrespective of ownership. In addition to scheduled bus services and coach

and rail operators, it includes taxis, private hire buses and coaches, and even the provision of school services (Vukan, R., 2007). Public transport consists of all transport systems in which the passengers do not travel in their own vehicles or vehicles owned by friends or family. Generally, it is taken to mean rail and bus services, although wider definitions would include scheduled airline services, ferries, and taxicab services: in fact, it is any system that transports members of the public. Public transport can be operated with road-based vehicles (buses), rail-bound vehicles (e.g. trams, trains, metro), on water (e.g. ferries) or via air. For the purposes of this thesis, we focus on road-based vehicles, but the techniques described can be extended to include all modes.

### *1.2.1 Public Transport Services Systems in General*

Many of the big cities in the world are facing serious traffic problems due to increasing traffic congestion, rapid development and car ownership. Traffic problems have environmental, social and economic implications for the community. The transport system has a major influence and impact on regional patterns of development, economic viability, the local and global environment, and on maintaining a socially acceptable quality of life (Gong Laing, et al., 2006). With the presence of traffic congestion on routes, people may prefer to use alternative transit modes other than private transport. Public transport systems bring many social benefits: they can provide mobility for those who cannot or prefer not to drive, including access to trade, employment, education or medical services. For many people, especially low-income families, public transport is the only source of transport. Therefore, the quality of public transport systems might heavily influence their daily lives. A public transport system can directly improve the quality of life by providing mobility and accessibility to many people without the huge environmental and financial cost associated with mass car ownership.

For more efficient use of the public transport system people need to know where the appropriate vehicles are and when they will arrive at a particular location. This will help them to plan travel and save time. During peak hours, buses often do not adhere to published timetables. This results in long and unpredictable waiting times, overcrowded bus stops and unhappy passengers. It also leads to an effect called 'bunching' (Daganzo, F., 2009), where there may be a long waiting period before a

vehicle arrives and it may be followed or even accompanied by one or more vehicles covering the same route. The increased waiting times directly contribute to bunching, as the next vehicle has more passengers to board and is therefore further delayed.

### *1.2.2 The Benefits to Public Transport Systems*

Public transport systems include various transport services available to the general public. These services can play various roles in a modern transport system and provide various benefits, including direct benefits to users and indirect benefits that result if transit helps reduce automobile travel. Public transport systems can help to provide solutions to a nation's economic, energy, and environmental challenges and help to bring a better quality of life. The benefits to public transport systems may include:

- 1- Providing mobility to people such as access to medical services, essential shopping, and education;
- 2- Reducing the traffic congestion and pollution resulting from automobile emissions;
- 3- Public transport is a relatively safe mode with a lower fatality rate in comparison to car travel under the same conditions.
- 4- Public transport systems contribute to overall economic development by providing employment opportunities, decreasing cost and increasing productivity.

The benefits and importance of public transport systems impact everyone, even those who may never board a train or bus. Public transport systems are essential to the economic and social quality of life of the whole community.

### *1.2.3 Types of Public Transport System Services*

In the transit industry, the public transport service can be provided in several operating configurations, such as a fixed-route service or a paratransit service (TCRP Synthesis 76, 2008):

- **Fixed-route service:** It's a transport service mode where a bus travels along the same route at regular times each day and has regular bus stops along the route. This type of service occurs where there is sufficient population and/or employment density to support higher transit volumes. Days of operation and service hours vary by route or according to transit user numbers.
- **Paratransit service:** Paratransit is an alternative mode of flexible passenger transportation that does not follow fixed routes or schedules. Typically, mini-buses are used to provide paratransit service. This service occurs where transit trips are served on demand with regular routing and scheduling of services, typically in lower population density areas, or to accommodate elderly or disabled riders.

New service concepts combining characteristics of both fixed-route and paratransit, such as deviated-route services, are being tested in some countries to provide some regularity of service and to improve transit accessibility for all riders (TCRP Synthesis 76, 2008).

### *1.2.4 Advanced Technologies for Public Transport Systems*

Public transport systems compete with private automobiles to move passengers. Recently, transport services operators have begun utilizing advanced technologies to improve their operations. Technologies such as geo-positioning hardware, computing techniques (software and hardware) and mobile communications offer new opportunities for improved public transport systems. These technologies promise to improve transit services by allowing operators to track their transit vehicles in an almost real-time environment. These advanced technologies can increase the level of communication between passengers and transit service providers so as to keep passengers informed of actual journey information, which in turn saves time and increases the credibility of transit services. In public transport systems, various

techniques such as navigation systems (Bratislav et al., 2007), real-time transit information (B. Ferris. et al., 2010; Brendan, N. and David L., 2004) and colour-coded traffic information (H. Gan, 2010) are examples of technologies which have been implemented in urban transportation.

Technology such as Automatic Vehicle Location systems (AVLs) (Predic, B., et al, 2007) determines the transit vehicle's location using any one or a combination of positioning technologies, such as Global Positioning Systems (GPS), dead-reckoning, signpost and odometer or radio navigation. Once the real-time position is measured, the location data can be relayed back to a central server via a wireless link (typically a cellular service). Figure (1-1) shows the architecture of a real-time bus-tracking system using various technologies such as computer technology, wireless communications technology and geo-positioning technology. The communication between transit vehicles and tracking servers enables transit operators to monitor and manage their fleets more efficiently.

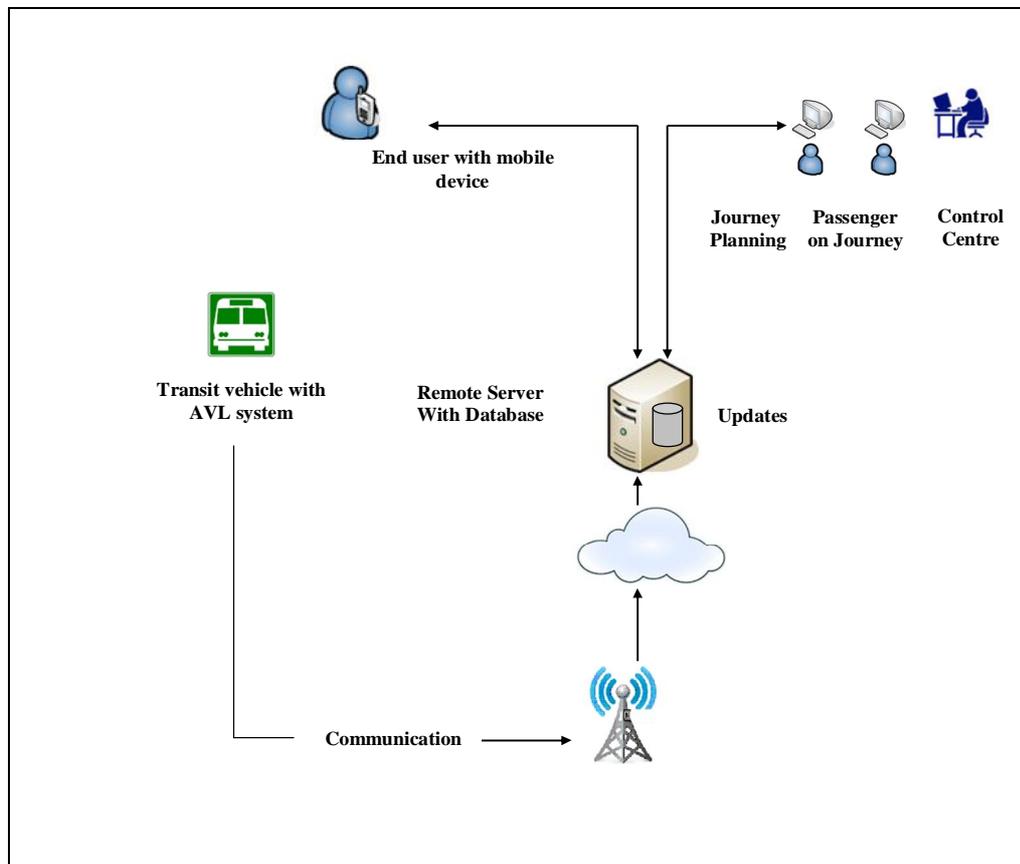


Figure 1-1 The architecture of a real-time bus tracking system using various techniques

As seen from Figure 1-1, transit vehicles are fitted with AVL systems transmit their locations in addition to other details to a central server through a wireless network. Global Positioning System is a worldwide free of charge service and is accessible to an unlimited number of users.

### *1.2.5 Challenges for Public Transport*

Transportation has long been recognized as having an impact on economic development. Factors such as levels of investment in transportation have been shown to have a positive impact on economic growth (Paratransit Resource Guide, 2002). The availability of reliable transportation services can have even wider implications: transport systems improve mobility for workers; they can be critical to the timely and affordable delivery of services such as health and education; they can also play a key role in maintaining social networks (Démurger, S., 2001; Parikesit, D., et al., 2006; Bradbury, A., 2006). For society as a whole, public transport systems are very useful. From an economic perspective, investment in transport can also drive economic growth (Glen, W. and Arlee, R. 2009).

The steady growth of community and the increasing population puts a large burden of the responsibility on public transport systems operators. It is the duties of the transport services operator to provide transportation services that meet public demands as well as the way to access these services. It is important for transport users (passengers) to access information about most bus schedules easily. Passengers want to view real-time updates on the current location and expected arrival time of their bus via web or mobile phone (NextBus, 2012; Metro Tracker, 2012; MyBus, 2012). This is particularly true for unusual journeys, journeys to and/or in unfamiliar places and for interconnecting services. Transit users need tools to easily interact with and access transit data based on their needs and their spatio-temporal contexts. The provision of timely and accurate real-time information to passengers in easy-to-understand ways can generally result in greater passenger satisfaction. This stems from the passenger's ability to feel more in control of their trip, including factors such as their time spent waiting and their perception of safety. Transit operators need to know where vehicles are at any given time and how they are performing.

People who are dependent on public transport systems in their daily life may want to plan trips in advance in order to minimise waiting time at bus stops and reduce the total trip time. Real-time navigation and door-to-door trip suggestions can be provided with transit services through pre-trip or trip planning tools: these provide transit suggestions based on real-time data such as user location and transit vehicle current location and timestamp. This would help passengers to plan their trips and catch the desired buses at the proper time. Bus timetables tell users of the transit system when buses are supposed to leave terminals and when they might arrive at particular stops, but actual departure and arrival times can vary from the scheduled times, so it is important for the users to see the current location of buses in real time. The aforementioned services empower transit users and create a better experience and effect a positive change in the public perception of transport systems. Estimated arrival time is the most important information for passengers (Rabi, G.M. and Mark M.M. 2006). To provide a reasonable estimation of bus arrival times, a robust algorithm is needed. The estimation should be made in real time, giving passengers an idea of when their bus will arrive. The provision of this information will help to attract additional passengers and increase satisfaction among transit users, which will ultimately result in a decrease in traffic congestion as more car users switch to the more efficient mass transit.

Reducing the high cost of operation to collect real-time transport data for monitoring transit vehicles in real time and the lack of appropriate and effective tools to provide the transit users with accurate real-time information are among the big challenges and obstacles facing transport service operators in order to provide better services. However, modern-tracking systems such as AVLs can capture the large samples of operating data required for performance analysis and management at a low incremental cost. In the past, it was very difficult to measure transit performance and costly to collect the necessary data. Whereas a large number of people were required to obtain a small amount of data in the past, substantial data can be obtained today from smaller numbers of people (El-Geneidy et al., 2010). The concern now relates to how this data can be stored and analysed to extract and create information relevant to the transit services in question. Where good quality data is captured, new analysis tools are needed that take advantage of this resource. Additionally, transit operators need tools to analyse and visualise this data in ways that enable them to calculate

metrics and summaries and to better assess and improve the Quality of Service (QoS).

The term QoS may entail many significant quality attributes or characteristics of the public transport system such as accessibility, availability, reliability, safety and comfort. Transit Capacity and Quality of Service Manual (TCRP Report 100, 2003) defined Quality of Service as “the overall measured or perceived performance of transit service from the passenger’s point of view” (TCRP Report 100 2003). Data gathered by transit vehicles helps to build up an archive of data that can be analysed and mined for information that can show the behaviour of the transport system over time, indicating problems such as vehicle bunching and delays due to congestion. In addition, to qualify for public subsidies, operators must report Quality of Service metrics to the government (Gwilliam, K., 1999). These are usually calculated manually, but the existence of a full archive of data provides the potential for automation.

In summary, many challenges associated with running effective public transport systems are: efficient monitoring and interventions to improve effectiveness; effective communication with users regarding actual bus journeys; prediction of actual journey by public transport modules; reporting performance of public transport to regulators, founders and users.

### ***1.3 Software Tools for Control, Analysis and Visualising of Public Transport Systems Operations***

The impact of computer science on transportation systems is still in its early stages, but in the last few years we have witnessed the significant impact of computer techniques (software and hardware) on surface transportation. Navigation systems, real-time traffic information, colour-coded traffic maps and real-time information about public transportation vehicles are some examples of the improvements in urban transportation brought about by technology. The recent advances in computing technology have made real-time bus tracking systems a viable application area. Computer software with integrated technologies is used in the transportation field to

design and implement Intelligent Transport System (ITS) applications that help in managing vehicles in transportation networks and improves transit services.

Computer-based data visualisation techniques help in enhancing dynamic or static transit data visualisation (Feng, et al., 2011). Dynamic visualisation of transit data allows operators to manage their fleet and avoid bus operational problems such as bunching or schedule/headway deviation. Potentially, the following computer technologies could be applied to a dynamic public transport management system:

- Web-based or mobile-based interface to display transit information in easy-to-understand ways;
- Data management systems to store and extract transit information;
- Advanced analysis and modelling computing (transit data is analysed and mined to build different models which capture performance and are used to extract transit information and evaluate the services);
- Visualisation and animation (computer software could be written to provide powerful tools for visualising and animating information using different views);
- Applying information systems and information technology semantics and standards in the transportation field;
- Wireless communication (this technology enables communication between computers and mobile devices where transit information can be delivered to the users);
- Client-Server architecture which helps in developing real-time transport applications.

To answer the challenges of the previous section tools are required. They can be created using software. Software tools can help in providing appealing views for visualising vehicle behaviour over time, as well as transit vehicle progress information with any deviations from the published schedules because of traffic conditions, breakdown or road accidents, etc. Software tools can also help in

calculating (QoS) metrics automatically. Using data analysis and mining techniques, bus arrival time models can be developed and implemented. For user convenience and flexibility, transit services must be interactive such that users can navigate to the transit region's map. Developing public transport software systems should improve confidence, reduce user anxiety, and add more credibility to public transport.

### ***1.4 Evolution of Public Transport Systems***

Transport industries have constituted one of the most important activities of men in every stage of advanced civilisation (Marshall, A., 1919). The importance of transport systems is increasing every day with the new development in the fields of transport infrastructure, traffic control, transportation engineering, computing techniques, communication networks and geo-positioning systems. The integration between these technologies can effectively help public transport systems to collect meaningful large amounts of operational data in real-time, which can be made available to the public. It also brings solutions to help in transit fleet management and performance evaluation. The list below summarizes the expected benefits of using the integrated technologies in public transport systems:

- Reducing operating cost, especially in data collection;
- Providing efficient and reliable data to transport operators;
- Helping to manage substantial increases in bus trips and passengers;
- Enabling transit operators to manage their bus operations on a real-time basis;
- Ensuring that consistent service levels are provided by bus operator;
- Improving the quality of real-time transit information provided to transit users;
- Building archives of historical data for more effective and detailed analysis;
- Helping in predicting expected arrival times in both pre-trip and en-route situations;
- Enabling transit operators to respond more quickly to emergencies;

## ***1.5 Aims and Objectives of the Thesis***

This thesis explores cost-effective computer software and hardware techniques in the area of public transport systems and improving transit services by developing tools for monitoring and analysing public transit systems. The main goal of this project is to develop a methodology for building a cost-effective public transport software system, which provides transit operators with various tools to monitor and manage their transit fleet and provide better services to the public. The developed system should make transit information accessible to users. The specific aims and objectives of this research can be written as:

- To identify the main attributes of a close-to ideal public transport software system and then determine how these ideals can be achieved using state of the art technology but at a reasonable cost.
- To develop a cost-effective public transport software system using a GPS device for positioning and GSM/GPRS for information transmission with features which can:
  - Track transit vehicles in a real-time environment;
  - Monitor transit vehicle performance;
- Delivering transit information to users through standard web-based and smart mobile devices and explore the potential of smart mobile phones devices to improve transit services;
- To implement accepted QoS. metrics to measure public transportation system performance.
- To explore new transport methods to visualise transit vehicle behaviour over time to help operators assess vehicle performance.
- To develop and implement bus arrival time prediction models which provide timely and accurate bus arrival times and evaluate their performance.

Thus, we are concerned with developing real-time map-based bus tracking systems using the data generated from GPS tracking devices and with communicating this

data to transit users. The system should offer an interactive interface for users to query and receive transit information. Transit users with internet-enabled smart phones can also receive transit information on a well-designed interface. We address the use of GPS tracking devices in the area of public transport systems. These devices are used for positioning and can integrate with wireless communication such as GPRS to communicate positional information to a central server. Data from these devices can be used to get detailed information of current bus locations, and can be used to provide information to algorithms that can predict bus arrival times at particular stops. Through this transit information system, we aim to provide transit users and operators with views and graphs which visualise vehicle behaviour and show the regularity of services.

We also investigate the use of computer software techniques to implement QoS indicators that can automatically calculate metrics for reporting and comparing QoS. Automated calculation of QoS will provide operators with an overview of transit system operations, providing an opportunity for better service provision. The main component of real-time bus tracking systems is a travel time prediction model which estimates the time when a vehicle or bus will reach a particular location, or the location where a vehicle will be at a specific time. We address issues related to developing and implementing bus arrival time estimation. These models should be dynamic and use road and traffic information to adjust times. Another of the motivations of this research is to investigate the use of smart and internet-enabled mobile phones to deliver and extract transit information using built-in sensors such as GPS or a digital compass. This will help transit users to access transit information and manage their journey time.

While routes are becoming more congested, it is important to attract people to public transport systems. Developing a dynamic real-time bus tracking system that can provide timely and accurate transit information to potential users is expected to increase the utilization of public transit. For transit operators, using real-time bus tracking systems will help to maintain the reliability of transit services and improve quality of service. Advanced technologies in computer software and hardware offer promise in providing transit operators with tools to manage and monitor their fleet in an efficient way.

## ***1.6 Contributions***

This thesis presents the development and implementation of a comprehensive cost-effective public transport software system that provides transit information in a close to real-time environment. Unlike other comparable work, in this research our system integrates computer software and hardware, and an off-the-shelf GPS-based AVL system with wireless communication networks. Our system provides transport operators with new innovative tools to improve the collection and visualisation of transit data dynamically and statically for real-time monitoring and performance analysis purposes. To improve public transit services in the context of passenger information systems, transit users are provided with tools that improve interaction via standard web browsers or smart-mobile phones. This thesis also introduces concepts such as haptic feedback as well as point-to-query systems to the area of real-time public transport systems.

In addition to visualising and depicting bus transit real-time location on a map and providing passengers with estimated times of arrival at particular stops, we improve transit services by integrating location based services with real-time transport systems allowing transit users to navigate the transport system in real-time and plan their trips efficiently. Our system applied routing functionality by using the Bing Map REST service and provide passengers with routing directions including the time required to walk through the shortest path to the nearest bus stop. Transit information can be accessed through a dedicated website, as well as through an application for mobile devices. In this research we improve the way of using a mobile phone in public transport systems by delivering real-time estimation of bus arrival at a particulate bus stop as we as using the haptic feedback to deliver transit information. Tools are provided for simulating and modelling transit system performance to provide transit operators with information on how well or badly the transport system works and system resources utilization, that is transit vehicle and stops are used. The thesis contributions can be summarised as follows:

- Developing a methodology to develop and implement a comprehensive cost-effective public transport software system (Shalaik, B and Winstanley, A.C, (2009)
- Providing efficient tools to improve transit data's visualisation (Winstanley A.C, Shalaik B. Jianghua Z. and Rebekah B. 2009),
- Developing, implementing and evaluating bus arrival prediction models to provide passengers with accurate estimated times of arrival (Shalaik, B., and Adam Winstanley, 2011b)
- Introducing and developing haptic-based feedback models for public transport systems (Shalaik, B., Jacob R, Mooney P, Winstanley A.C , 2012a)
- Developing a simulation-based evaluation model for real-time public transport systems (Shalaik, B., Jacob, R. and Winstanley, A.C, 2012b)

## ***1.7 Structure of Thesis***

Chapter 2 discusses the main attributes that must be available in a close to ideal public transport software system. Chapter 3 details a literature review of research publications of existing public transport information and control systems. The technologies used in intelligent transportation systems are discussed. Algorithms and models used to predict vehicle transit information are reviewed. In addition, passenger information systems as a means of delivering information to the transit user are reviewed. Chapter 4 addresses the performance of public transport service delivery from the perspective of (QoS) and service reliability. We describe the techniques and tools that we have developed to be used by transit operators to visualise and analyse transit data for better QoS. measurements and transit service improvement. Chapter 5 introduces models and techniques that enable passengers to easily interact with public transport systems via a standard web-browser or mobile devices to extract the desired information. The concept of integrating real-time bus tracking systems with pedestrian navigation systems is discussed. Chapter 6 describes techniques by which we tackled uncertainty associate with transit services. In this chapter, we discuss the process of developing and evaluating bus arrival times prediction models. Chapter 7 describes the design, implementation and overall

integration stages of the public transport software system and highlights its major characteristics. Chapter 8 discusses the characteristics of the system and results obtained. Chapter 9 concludes this work and suggests future work that may be undertaken to improve this system.

## **Chapter 2 Attributes of an Ideal Public Transport Software System**

### ***2.1 Introduction***

To increase the usability of public transport systems they need to be updated and improved in their operating procedures. This can be possible using recent computer technology including mobile computing advancements and communication technology. Public transport systems must have attributes and specifications to meet the requirements of transport systems stakeholders such as passengers, operators and regulators. Public transport software systems are close to ideal if they have several key characteristics and attributes that help in improving transit services. Among these attributes is the cost-effectiveness in terms of collecting transit data and providing passengers with accurate information in an easy and accessible way. Besides providing necessary information, public transport systems must include facilitating the analysis of transit service performance in real time and historically; collecting information needed to perform system planning, such as running times, and scheduling; and providing vehicle locations to emergency management. Several attributes must be provided in the transport system so that the system can service the public efficiently. In this chapter, we identify and discuss the main attributes of a public transport system and their importance in the development of transport services.

### ***2.2 Attributes of an Ideal Public Transport Software System***

An ideal public transport system is one that can help to efficiently schedule and optimise operations to avoid operational problems such as bus bunching. Several key attributes should be provided in public transport software systems which make transport data available and accessible to current and potential users through various media. Bus arrival time prediction is an important part of public transport systems; thus, software systems should have the ability to predict bus arrival times at particular stops, and this can be achieved by employing prediction methods and

algorithms. Public transport software systems should provide operators with powerful tools to visualise and analyse data to characterize service problems and help improve service planning and operations control. Figure (2-1) illustrates the main attributes and features of an ideal public transport software system. These attributes may include:

- Cost-effectiveness (TCRP Synthesis 48, 2003);
- Tracking transit vehicles on a real-time basis (B. Ferris, 2011);
- The ability to visualise transit data for extracting information in an easy to understand way (Ricardo H., 2009);
- Providing passengers with timely and accurate real-time information (TCRP Synthesis 48, 2003);
- Provides interaction models based on transit users' needs (Darren, M. and Yvonne, C. 2009);
- Data archiving and reporting tools to allow more effective detailed analysis (Bertini, R., & El-Geneidy, A. 2003);
- Tools to measure QoS and evaluate system reliability (Crout, DT., 2007; Noorfakhriah Y., and MadzainN., 2011);

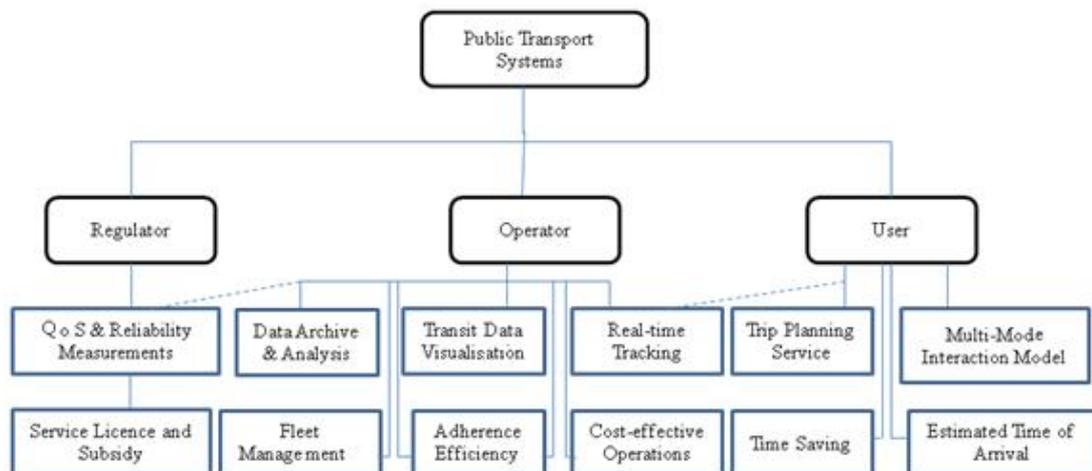


Figure 2-1 The basic models of use of an ideal real-time bus tracking system

As we can see from Figure (2-1) the attributes of an ideal public transport system are shown, these attributes should be available in the transportation system and their advantages are provided to the system stakeholders. Passengers/transit users need tools for real-time tracking, multi-mode interaction and provision of real-time information like estimated time of arrival. Operators are more interested in collecting, visualising and analysing transit data. Public transport services are usually funded by government subsidies and services are normally regulated so that transport systems regulators are more concerned with the Quality of Service (QoS) provided.

### *2.2.1 Cost-effectiveness*

Deploying an effective public transport system for tracking and managing bus operations has always been a desirable objective for bus operators and users but the associated technology was previously inefficient and expensive. Recently, developments in the areas of the Global Positioning System for accurate and reliable vehicle position determination and GSM/GPRS systems for wireless data communication offer new opportunities for the development of public transport systems. The vehicle location sub-system is of crucial importance for an effective public transport system, as it provides up-to-date information regarding transit vehicles. Technology such as GPS is the obvious choice, as Commercial Off-The-Shelf (COTS) GPS receivers can identify vehicle position with reasonable accuracy at a very low cost.

Since the bus location unit must be on board for receiving and transmitting information, some method for real-time wireless transmission of vehicle data has to be adopted. General Services for Mobile Communications (GSM) service providers have developed networks that cover urban areas. General Packet Radio Service (GPRS) is a GSM data transmission technique that does not set up a continuous channel from a portable terminal for the transmission and reception of data but transmits and receives data in packets. As GPRS is “always on” the data transmission is faster because network capacity is used more effectively. Also, users are charged only for data transmitted, not for the time that the unit is online. GPRS data transmission from a number of transit vehicles to a central server can be achieved using the TCP/IP protocol. These affordable and low-cost technologies can

significantly improve public transport systems and contribute to reducing the cost of developing and updating of these systems.

### *2.2.2 Tracking transit vehicles on a real-time basis*

An ideal public transport system has real-time tracking. Real-time vehicle tracking can be achieved through the collection of operational data, especially vehicle position, which is aggregated from transit vehicles equipped with positioning devices, and transmitting this data to a central server. This data is then visualised via a web-based map interface or mobile-based interface. Real-time tracking systems help people using public transportation by showing them which bus they should take to reach a specific destination and where this bus is currently en route. Real-time tracking of transit vehicles may also be useful for transit operators for the application of proactive control strategies such as bus holding and expressing, after detecting schedule/headway deviations in the system (Shalaby, A., and Farhan, A. 2004). An ideal public transport systems must provide effective tools to enable the operator to track their transit fleet in real-time.

### *2.2.3 Providing passengers with timely and accurate real-time information*

One of the main objectives of any public transport system is providing transit users with relevant transit information in an accessible way. (Zhang, L et al., 2010) stated that providing real-time transit information relieves travellers' stress and reduces waiting time when provided prior to travel. (Grotenhuis, et al., 2007) showed that the provision of real-time transit information is a main requirement of passengers. (Mark D., and Nigel H., 1995) discussed the impact of real-time transit information on travel path choice and the results suggest that real-time information yields only very modest improvements in passenger service measures such as the origin-to-destination travel times and the variability of trip times. Travel information availability is an important factor for increasing the ridership because a lack of detailed and timely information can act as a barrier to people's use of public transport systems (Brian C', and Margaret O'M., 2009). Traffic congestion, weather conditions and variation in passenger demand can lead to consequences such as service unreliability and deviation from timetables. Therefore, transit users prefer to

receive real-time transit information rather than rely on static timetables (which take no account of unpredictable variations). Transport information systems are crucial for informing passengers of real-time information. (Brendan N., and David L., 2004) reviewed and classified various types of transit information systems through an adaptive stated preference survey to determine the value of information for passengers. In this study, the authors found that, by removing the anxiety barrier and providing transit information to passengers with regard to their location, destination and arrival time, there is no reason for the public not to use transport systems.

In a study to create a refined method for evaluating passengers' benefits from real-time transit information, (Ryan et al., 2011) concluded that transit information provided over the internet can save passengers waiting time at a bus stop. (Caulfield, B. and O'Mahony, 2009) discussed the need for real-time information at public transport stops. In their study, they examined individuals' preferences between real-time information options and investigated how this choice varies between bus and rail users. The provision of transport information can improve the ridership and enhance transport system usability. (B. Ferris et al., 2009) presented the results from a survey of the 'OneBusAway' transit system, which provide users with transit information. The results of this survey show that respondents have an overall increase in satisfaction with public transit, make more transit trips on a weekly basis, spend less time waiting for vehicles and have increased feelings of personal safety when using public transport software systems. (TCRP Synthesis 48, 2003) stated that after the deployment of "Automatic Vehicle Location systems" (AVL), transit agencies recognized that data from an AVL system could be used to provide customers with real-time transit information such as predictions of bus arrivals. Passengers need to know which bus they should take to reach their destination, where it is currently located and when it will arrive at a particular bus stop. Real-time transit information is essential for passengers to plan their trips efficiently, so ideal public transport systems need to have tools to deliver real-time transit information to their customers in easy to access ways.

#### *2.2.4 Multi-Mode on Transit Information Interaction*

To ensure an efficient use of public transport services, the availability and usability of information relevant to the passengers at any given time is very important (Shiri A., and Emily., F., 2010). Public transport systems should be interactive and transit information must be provided while understanding that current or potential users are in different spatio-temporal contexts. Often the same type of information must be provided in different, easy to understand modes. Web-based services are now considered an essential tool for public transport software systems to deliver/retrieve static and real-time transit information. In addition to web-based systems, public transport software systems can be more flexible in terms of provision of transit information to passengers with smart phones (James B., et al., 2011). The main advantage of this is that passengers can use the transport system on their mobile devices to reduce anxiety and receive transit information throughout their trip until they reach their final destination. Ideal public transport systems should make transit data accessible via various media such as standard web browser or handheld device such as mobile phones.

#### *2.2.5 Visualising Transit Data for Information Extraction and Problem Detection*

By adopting technologies that enable bus locations to be tracked from a central location in real time, it is now feasible for transit systems operators to monitor their fleet in real time and coordinate the movement of buses along their routes. To achieve better management and transit operations control, operators need efficient tools to analyse, visualise and summarise transit data. Transport software systems must provide operators with tools to visualise transit vehicle behaviour so that they can detect and classify problems. Visualising transit vehicles' behaviour over time also allows the operator to better assess their performance and improve the quality of their service. An ideal transport system must have tools to visualise transit data on a static or real-time basis through tables, graphical views, data plots or interactive maps. Visualisation processes can be off-line (historical) or on-line (real-time) and integrated with real-time data sources. Data visualisation will help to show the regularity of the service, as poor-service phenomena such as vehicle-bunching and erratic service intervals are easily detected by visualisation. Timetables can be

plotted in an easy to understand way, providing comparisons between the actual running and the scheduled services.

### *2.2.6 Quality of Service (QoS) Measurements and Reporting*

For an ideal public transport system, additional software tools need to be in place to measure performance, quality of service, and the effectiveness of schedules and routes, and to provide current service status information to passengers. Different benefits may require different technologies and software functionality. Quality of Service metrics have generally been calculated manually (TCRP Report 100, 2003) due to the lack of automation and difficulty of data collection, but now transport software systems give the potential for automation. This also helps transit operators to report QoS metrics to the regulatory authorities. Public transport software systems must have the capability to provide transit operators and supervisors with service reports that give vital information such as vehicle behaviour and performance. These reports should be easy to use and accessible, allowing operators to get the information they need when they need it. Reporting tools are vital to solving problems and improving service and operations. The information provided through reports helps to determine where, why and how problems occur, allowing transit operators to determine ways to improve transport operations.

### *2.2.7 Building an Archive of Transit Data*

In addition to the provision of real-time transit data, public transport software systems must have the ability to build an archive of transport data. In the past, to measure transit performance, it was difficult and costly to collect the necessary data. A large number of people were initially needed to obtain a small amount of data. Today, a small number of people can collect large amount of data (Bertini, R., & El-Geneidy, A. 2003; Mathew, B., et al., 2007). With the availability of rich archived data, the concern is related to how this data can be analysed and used to create information that is relevant for service planning and control (Levinson, H.W, 1991). Archived transport data can be analysed and used to help in improving bus routes, evaluating system performance and even in developing models to predict future travel time (TCRP Report 113 2003; Karbassi, A. and M. Barth 2003). Storing transport data that is collected over time can provide the opportunity to complete off-

line analysis as well as recognize trends in the data. Analysing archived data allows transit operators to identify problems qualitatively and quantitatively and compute transport performance measures. Archived data can also be used for track playback and further analysis and statistics. The use of an efficient database capable of managing, handling and retrieving data easily can help to archive transit data for better analysis and planning.

Ideally public transport should have tools that are capable of gathering an enormous quantity and variety of operational, spatial, and temporal data that, if captured, archived, and analyzed properly, holds substantial promise for improving transit performance by supporting improved management practices in areas such as service planning, scheduling, and service quality monitoring. Historically, however, such data has not been used to its full potential (TCRP Report 113, 2003). As shown in Figure (2-2) different public transport system components provide a variety of service and information to passengers, transit operators and regulators alike.

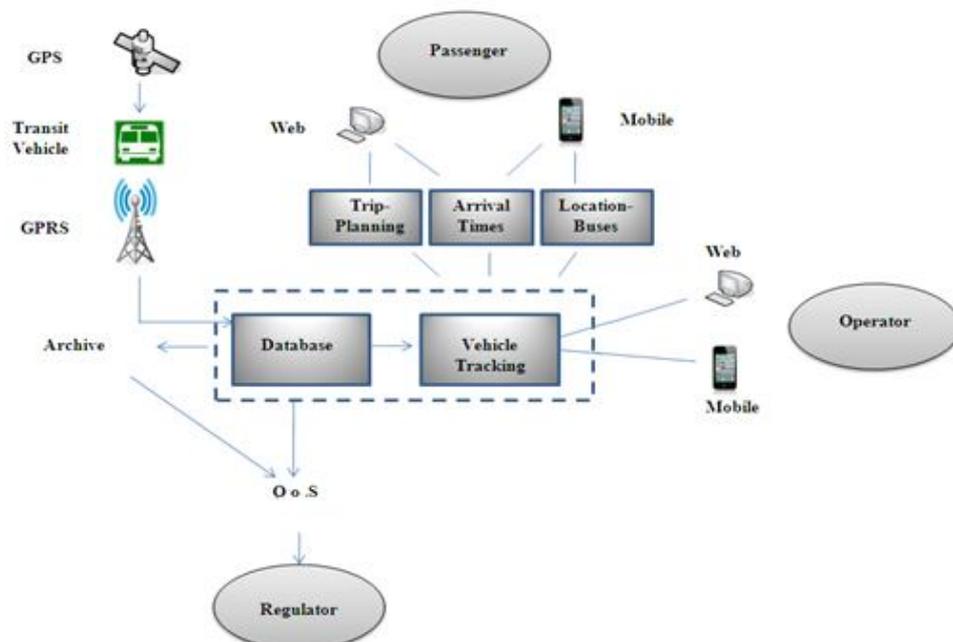


Figure 2-2 Various information provided by an ideal public transport software system

Figure (2-2) highlights that public transport software systems can provide a variety of information useful for passengers, transit operators and regulators alike. Passengers can access information through mobile phones or web browsers, transit

operators and supervisors use transport software systems to provide regulators with reports and summaries regarding transit system performance. The potential of public transport information systems is widely recognised and the enabling technology is increasingly available and capable. In the transportation industry, commercial systems are already used to improve planning and real time transit operations control.

Improving current public transportation systems can be achieved by adopting new technologies in computer software and hardware as well as communication networks. These technologies can help in improving existing transport systems by providing real-time transit information to the public when and where they need it. Computer software and hardware technologies as well as low-cost communication networks can improve the existing public transport systems or help to develop new close-to-ideal systems. An up-to-date public transport software system would provide new tools for upgrading and improving public transport systems, allowing these systems to provide full services and meet all passengers' and operators' requirements.

### ***2.3 Conclusion***

In this chapter we have identified and discussed the main attributes of an ideal public transport system. The definition and discussion of the main attributes of transport systems is an important step prior to any update or development of a modern almost complete public transport system. In the next chapter we will look at the state of the art in current systems and assess how far they are from the ideal system.

# **Chapter 3 Public Transport Information and Control Systems**

## ***3.1 Introduction***

In the previous chapter, we have identified and discussed the main attributes which must be provided in an ideal public transport system. In this chapter, we will review the progress that has been made to improve public transport systems. Moreover, we will discuss the development of locating systems, and the means of communications used in public transport systems. Also, we will consider the applications of AVLs and the capabilities of these systems, in particular we will mention improvements that could be made to several aspects such as collecting a significant amount of transit data, transit data visualisation and measuring, that could lead to improving transit vehicles performance. We will also discuss other aspects related to public transport systems, which includes bus arrival/departure prediction models and their development, transport system reliability, real-time transit data provision, trip-planning services and mobile applications in transport systems. The development of these aspects helps in building transport systems that are able to improve transit services and facilitate the use of transport systems.

## ***3.2 Advanced Public Transportation Systems (APTS)***

The impact of computer technologies (computer software and hardware) on transportation systems is not as strong as on other disciplines such as finance or business (Ouri W., and Bo Xu, 2010). Recently, due to technological advances in wireless mobile communication, computing technology and geo-positioning technologies, there have been widespread implementations of computer and communications techniques in the transit industry.

APTS technologies are a collection of technologies that increase the efficiency and safety of public transportation systems and offer users greater access to information on system operations (RSPA, 2000). APTS employs Intelligent Transportation Systems (ITS) technologies in order to improve operational efficiency, cost savings,

safety and quality of service or other transit measures of performance. ITS is defined as the application of computer and electronic technologies to the transportation network to provide effective solutions to current transportation challenges (Stephen, E. 2010). The goal of ITS is to offer significant improvements in safety, productivity, accessibility and mobility, while establishing an intermodal surface transportation system. Figure (3-1) shows an example of ITS application in public transport system.

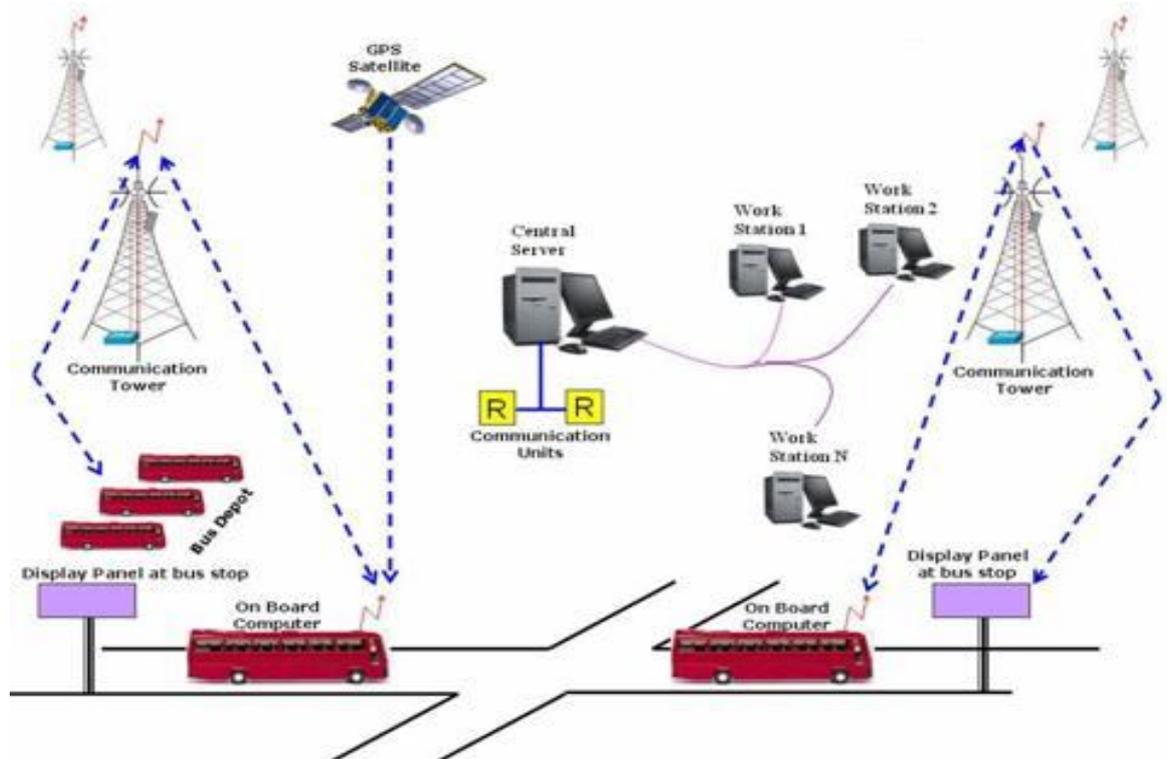


Figure 3-1 An example of ITS application in public transport system (Source: <https://www.google.ie/img/ghp?hl=en&tab=ii>)

As we can see in Figure (3-1) buses equipped with on-board devices determine its location and send this data to a main control centre, which in turn contains the workstations. Wireless communication networks can help to display data about buses such as arrival times or the bus current location on electronic boards at bus stations.

APTS applications offer the potential to improve services by providing greater advantages to service providers in terms of managing and controlling bus transit

operations. APTS applications have the potential to significantly change the way transit services are provided to transit users and the manner in which these services are used. Popular technologies such as Automated Vehicle Location (AVL) systems, Automatic Passenger Counters (APC) and Electronic Fare Payment impact on bus transit operations in a variety of ways.

### ***3.3 Automatic Vehicle Location Systems (AVLs)***

To improve transit services, operators of transit vehicles must have feedback on the performance of their transit system. The idea of tracking transit vehicles grew slowly after World War II because the demand for transit transportation declined and labour costs rose (Roth, H., 1977). Transit operators need to be able to identify and locate specific vehicles while the vehicles are in service. Automatic Vehicle Locations systems (AVLs) are the means for determining the geographic location of a vehicle and transmitting this information to a point where it can be stored and used with certain software and database applications. These systems combine vehicle location and communications systems to track the locations of a fleet of vehicles. AVLs have been used by transit agencies for decades with varying levels of technological complexity (Zhong-Ren, P. et al., 1999). In the past, transit system operators used manual systems to monitor their fleet. Individuals would stand at main points on the street to monitor the performance of the buses (TCRP Synthesis 22, 1997). These men, known as point men, used public phones as a means of communicating with a control station and of providing information based on their observations.

Many transit agencies have adopted AVL systems to track their fleets and provide transport users with a reliable and credible service. Modern AVL tracking systems should be automatically configured to transmit location data at a set time interval. AVL systems solve the problem of real-time vehicle tracking using a variety of radio communication networks. The main functions of AVL systems are to:

- measure vehicle location
- transmit vehicle data to a central server

The location is determined using positioning techniques such as GPS, 'Signpost', 'Dead Reckoning' and 'Radio Navigation/Location' (E., Fallon., 2000). The

transmission mechanism, the process by which the vehicle and the management centre exchange data, could be executed using radio (analogue), cellular (analogue and digital) or satellite (digital) communication technologies. Additionally, other methods use a combination of transmission technologies, but at a higher cost compared to a single technology. Most commonly, vehicle-tracking systems consists of AVL fitted or installed in the vehicle (In-Vehicle Unit) and a remote server. The transit data is transmitted to the remote server using a GSM/GPRS modem or a direct TCP/IP connection protocol with remote server through GPRS. The remote server also has a GSM/GPRS modem to receive vehicle data and store this data in databases.

### *3.3.1 Locating Systems*

Currently there are four different types of AVL locating systems which are in use. The use of these systems has evolved with the introduction of better products and newer systems. The types of systems in use include signpost, dead-reckoning, radio navigation and GPS. These types of AVL systems can be used as standalone or in combinations. For example, GPS technology is used in combination with dead reckoning. Normally GPS is used but it is substituted with dead reckoning when no GPS signal is available.

#### *3.3.1.1 Signpost System*

The signpost system consists of a series of sensors or beacons placed along the route of a vehicle. Each of the beacons emits a low-powered radio signal with a unique ID. The passing vehicle has a special receiver built in, which can decode the ID of the beacon. The vehicle's receiver uses the radio to transmit the code and time of the last signpost signal received. At the control station, the AVL system is updated to reflect the information that, at the time the vehicle received the signpost signal, the vehicle's location was approximately equal to the location of the signpost. Vehicles participating in this type of tracking system transmit a signal uniquely coded for each vehicle. (S., Riter, and McCoy, J., 1977). The late 1960s saw the first use of a signpost system with a transit fleet AVL system by the Chicago Transit Authority. In 1989, the Ottawa Canada 'OC' transit system used signpost systems to track their transit fleet. In the early stages of AVL development, the signpost technique was the

most advantageous positioning technique in terms of both implementation and performance criteria. Due to the immediate advantages of signpost systems, many transit agencies began using signposts to implement their own AVL systems at that time. Besides the advantages that signposts can provide for tracking transit vehicles, there are some disadvantages, such as the expense of installing sensors wherever vehicles need to be located. In some instances, the signal cannot be detected when a signpost is damaged or a signal is blocked. (The vehicle may also be diverted around the signpost system and also the signpost system requires continual maintenance to keep it operating properly).

### *3.3.1.2 Dead Reckoning*

Dead reckoning has been used in position location for a long time. It is a navigational term first used by seafarers charting oceans in the eighteenth century (Randell, C. et al., 2003). Navigators would determine their current position by calculating the ship's bearing and speed since the last known position. Dead reckoning techniques are also used to calculate the position of motor vehicles. The distance travelled is calculated by subtracting the odometer reading at the last known position from the current odometer reading. The bearing of the vehicle is determined by using some type of compass device or by knowing a pre-determined route. Locating vehicles with dead reckoning can be difficult because many uncontrollable factors can affect the validity of the position calculation. For better calculation, odometers must be very precise and initially calibrated, but other factors, such as tyre pressure and road conditions, can affect measurements. Since positions are calculated from the previous position, errors can accumulate rapidly and cause miscalculation. Dead reckoning can also be integrated with GPS for location determination when no GPS signal is available (Silvester and Adeline 2004; Ochieng, et al., 2010).

### *3.3.1.3 Radio Navigation*

Radio Navigation Systems, like signpost systems, rely on fixed reference points. In radio navigation, the constant speed of light and the propagation delays of radio signals are used to find the ranges from a vehicle to fixed sites. Radio navigation has been used for many years to aid in aviation and marine navigation, but it was not considered for use in land AVLs until the 1970s, when it became economically

feasible (Roth, H. 1977). There are several ways to use radio signals to determine the location of a vehicle. They can be used either at the vehicle or at fixed stations to calculate vehicle location. When a vehicle's position is determined at a fixed station, the system measures the absolute time the signal takes to travel from that fixed station to the vehicle and back. The absolute times found by a minimum of three stations are sent to a central control station, where the times are used to calculate the distance from each fixed station to the vehicle. These distances are treated as the radii of circles with the stations at the centre. The intersection of all the circles described by the stations gives the location of the vehicle. When measurements from just three stations are used, the technique is referred to as 'tri-lateration'. If more than three fixed stations are used, the technique is called 'multi-lateration'. Increasing the number of stations decreases the estimate error in the measurements (S., Riter, S. and McCoy, J., 1977).

One advantage of radio navigation is that it can be used for applications on land, in the air and on water. Another advantage of a national radio navigation system is that it offers automatic vehicle location for 24 hours each day. Thus, it eliminates restrictions that other systems might impose on where vehicles may travel and still be tracked. When GPS was still in the planning stages, radio navigation systems had already been implemented and were producing satisfactory results in aviation and marine applications.

#### *3.3.1.4 Global Positioning System (GPS)*

In real-time public transport systems, transit vehicles are mostly equipped with tracking devices that contain GPS systems and are connected through dedicated wireless networks (satellite, terrestrial radio or cellular networks) to a central server. The GPS is a satellite-based radio-navigation system developed and operated by the U.S. Department of Defence (DOD) (Zhong-Ren P. and Oliver J. 1999). GPS provides the user with their three-dimensional position, their current velocity and the exact time. The GPS system consists of twenty-four satellites orbiting the earth in six circular orbits. Figure (3-2) shows these twenty-four GPS satellites. The satellites are arranged so that at any given time, there are six satellites within range of a GPS receiver. The control segment of the GPS system consists of one master control station in Colorado USA, with five ground control stations and three ground

antennae located around the world. The monitor stations passively track all satellites in view.

Each satellite's broadcast signal is continuously sampled. These samples are then forwarded to the master control station, which calculates extremely precise satellite orbits. The orbit calculations are formatted into navigation instructions, which are uploaded to the individual satellites via the ground antennae. Simultaneously, each of the satellites continuously broadcasts an exact position and time signal. The GPS receiver receives messages from at least four satellites and measures the time delay for each signal. From these values, the GPS receiver can calculate the user position and velocity. GPS devices can identify locations with high accuracy up to 10 meters.

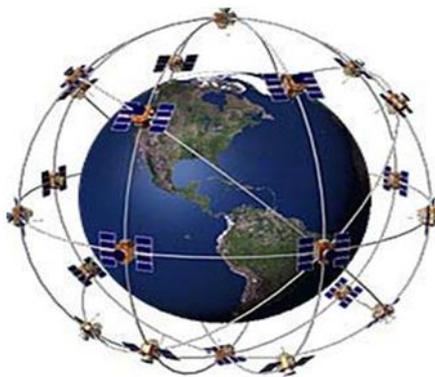


Figure 3-2 Twenty-four GPS satellites

The European Union (EU) introduced a free global positioning system that it claims is almost five times more accurate than the U.S. system currently in use. Called the European Geostationary Navigation Overlay Service (EGNOS) (Dragos C., and Andrei M., 2010; Z. Hunaiti., et al, 2006), the system uses three satellites and a ground network of about 40 ground positioning stations and four control centers. The U.S. military-run GPS system, in widespread use across the globe, offers a 10-meter accuracy level, but EGNOS promises to fine-tune this experience and deliver accuracy levels to around 2 meters. It is expected that the next generation of GPS-enabled smartphones will benefit from the improved accuracy of EGNOS. Some standalone GPS devices might soon use EGNOS as well, given that the manufacturers release firmware updates to support the system.

### 3.3.1.5 Differential GPS

Differential GPS (DGPS) is a technique used to increase the accuracy of GPS receivers to within one to three metres. The technique involves placing a GPS receiver (a reference receiver) in a known physical location. The reference receiver collects data from all the satellites in view and performs error corrections on the signals, checking the actual location against the broadcast location. These corrections can be either recorded (used for post-processing of signals) or broadcast in real-time via radio (Daniel J., 1996). Figure (3-3) highlights using DGPS for correcting GPS signals. As we can see from Figure (3-3) if a GPS (reference receiver) device is placed in a location with known coordinates, error corrections can be performed on the signals and then broadcasted in real-time via radio.

DGPS is used in the transportation industry for more accurate positioning of transit vehicles to help vehicles maintain their schedules regardless of traffic congestion.

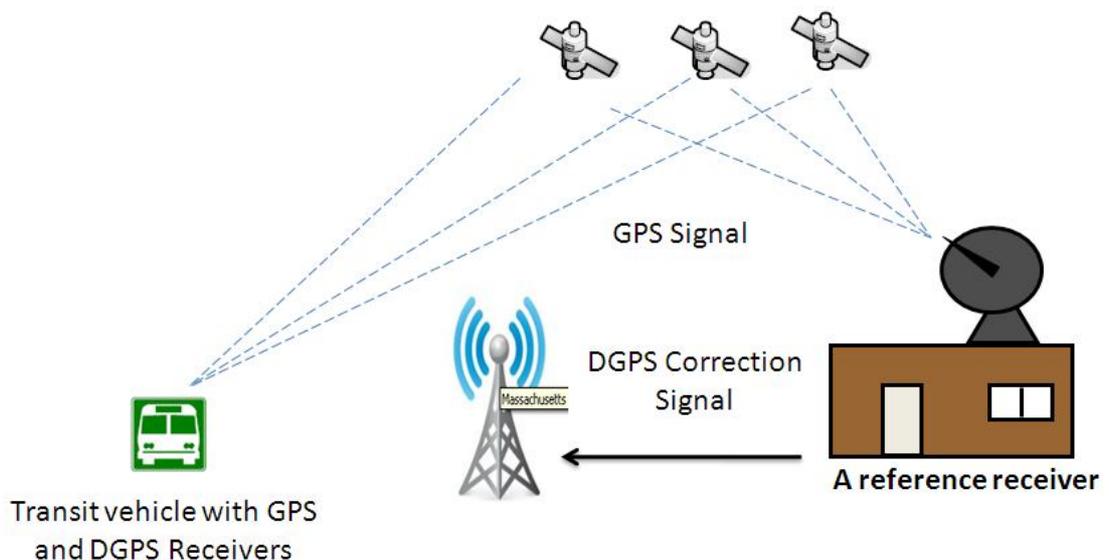


Figure 3-3 DGPS for correcting GPS signals

### 3.3.2 Applications of AVLs to Public Transport Systems

AVLs have been widely used in public transport systems to locate vehicles and provide transit information on vehicle status. The provision of timely and accurate transit information is important because it attracts additional users and increases the

satisfaction and convenience of transit users. Such information assists users in making plans and enables them to make better pre-trip and en-route decisions. The first use of AVL technology in transit was in London, England in the 1950s (TCRP Synthesis 48, 2003). In the 1970s and 1980s, an early generation of bus AVL technology was deployed using a wayside signpost location technique (TCRP 73, 2008). By the late 1990s, transit agencies were generally adopting GPS-based AVLs, which had been operational in 1995. GPS-based AVL systems addressed some of the key limitations of signpost-based AVLs by eliminating the need for the wayside signpost infrastructure. However, in some cases, a combination of GPS and another positioning technique such as dead reckoning has been considered for use where GPS signals cannot be picked up by vehicles due to signal interference from tall buildings in urban areas.

Increasingly, public transportation applications use GPS/DGPS as a main tool for locating transit vehicles. An additional use of AVLs in transit systems is to collect data from buses. The success of AVLs as a means of data collection makes it a key component of advanced public transport systems. Data collected by AVLs is also used to depict the current location of transit vehicles on maps which helps in transit data visualisation. Archived AVL data can be used to improve the supervision practice and enhance bus service reliability by measuring the performance of the transit system and reporting this performance to external funding and regulatory agencies (TCRP Report 113, 2003). Some transportation projects have used GPS-based AVL data to create innovative transit tools in Seattle area bus service by providing users with real-time arrival information (TCRP Synthesis 48, 2003).

### ***3.4 Communication Networks for Transport Systems***

The communications systems are the technologies that allow the sharing of information between the vehicle and the transit central server, between the vehicle and field-installed technologies, such as traffic signal controllers for bus signal priority or dedicated bus lanes, and between service operators and passengers. Communications systems also make it possible for the transit central server to monitor vehicle performance and to exercise control over vehicle movement and behaviour. There are a wide variety of communication systems for sending voice and data (e.g. analogue, digital, cellular digital packet data) between transmitter and

receiver, including two-way radio and short-range communications, General Packet Radio System (GPRS) for data transmission or Short Message Service (SMS) (Nick, P. and Elias, S., 2001). Furthermore, the type, quantity and transmission cost of data relayed between vehicles and field-deployed devices and between vehicles and the transit central server varies from application to application. Some basic properties of communications systems, however, are common to all applications. Figure (3-4) shows an example of communication networks for a public transport system.

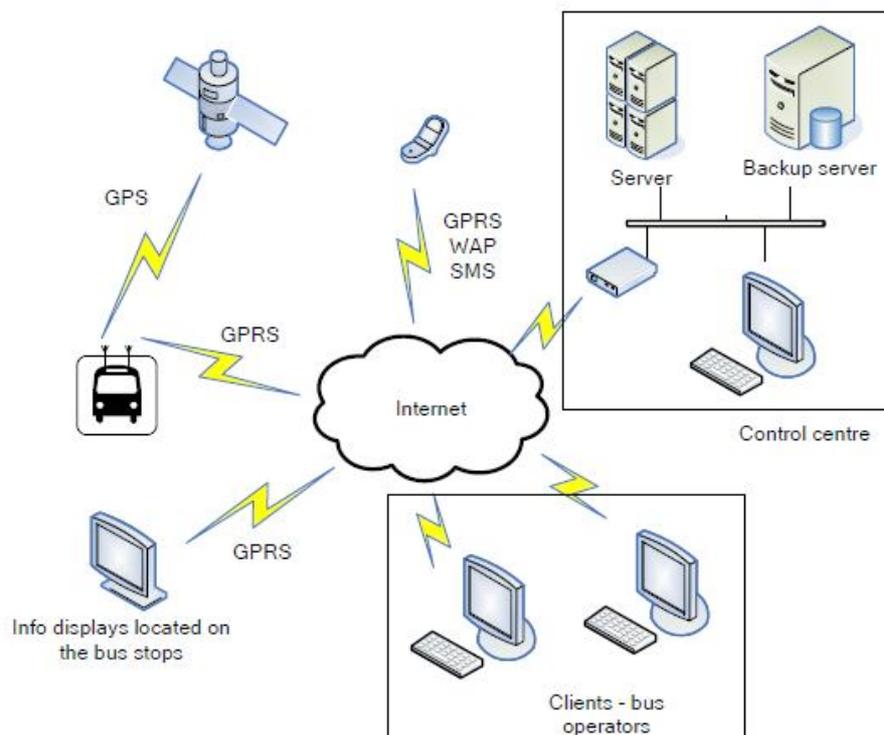


Figure 3-4 An example of communication networks for public transport system  
Source: (Bratislav et al., 2007)

As we can see in Figure (3-4) it shows the use of Internet to connect buses with the control centre and to link the user with a transport system, as well as connecting information display boards with the operator using the communication system such as GPRS.

Communication technologies can lead to an increase in the efficiency of the transport system and offer transit users greater access to information on system operations. Communication technologies are highly integrated and facilitate the transmission of rich data sets for analysis and service improvement. Different transit applications,

such as fleet management systems, passenger information systems and electronic payment systems, have been developed using these technologies (Jason D., et al ,2011; Peng C, Shuang Liu,2010).

The primary high-level goals of using communication technologies are as follows:

- To improve communication with transit operators toward better response and improved dispatch;
- To improve the ability to track the locations of transit vehicles in real time in order to improve services and planning;
- To make travel more convenient for transit users and to improve the visibility of transit services through the implementation of a real-time passenger information system;
- To address growing demand for service without adding additional personnel or equipment;
- To improve the QoS;
- To provide more effective management and accountability.

### ***3.5 Techniques for Transit Data Visualisation***

One of our goals in this research is to take advantage of AVL capabilities by collecting a huge amount of transit vehicle operational data to improve the analysis of displaying transit data graphically and pictorially. Visualisation is a process of transforming data into a visual form, enabling the user to better understand and extract information. Visualisation gained widespread currency in the mid-1980s when for the first time computer graphics was linked to supercomputer processing, particularly in scientific contexts (Michael, et al, 2004). Visualisation is a very broad term and its styles vary enormously with context. In transit industries, visualisation encompasses many definitions and uses, it plays a key role in displaying raw transit data as well as operations performance data that contains detailed and accurate information. Visualisation is not only valuable in identifying potential problems; it also helps to improve service reliability.

Many transit agencies have found that visualising transit data is necessary for planning, management and analysis purposes. (Langendorf, R., 2010) Argues that the ability to understand complex phenomena often requires investigation from multiple viewpoints using a variety of data sources and that visualisation can serve to enhance communication among the participants in the problem solving process. Transit performance monitoring applications can readily embrace visualisation techniques and concepts, with beneficial results. Transit data can be visualised through static or dynamic frameworks using tables, maps, data plots and other graphical outputs which provide users and operators with a variety of information in easy to understand ways. (Wei F. et al, 2010) provide ways to summarize and visualise bus route operations data using colour counter diagrams and a dynamic interactive bus monitoring visualisation framework based on the Google Maps platform. Figure (3-5) shows on-time performance data using a box-plot graph. Each box-plot shows the range of the schedule adherence (actual departure time minus scheduled departure time) values for each stop during the time of measurements.

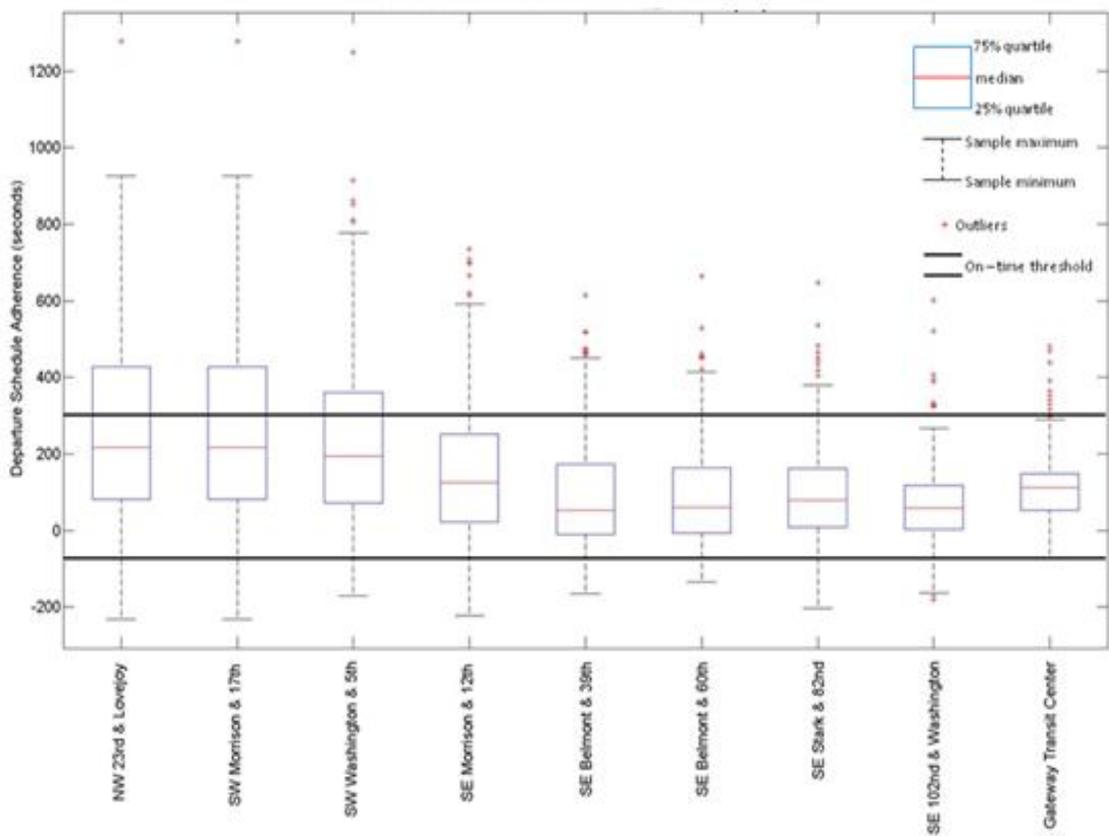


Figure 3-5 On-time performance data using a box-plot graph (Source: Wei F. et al, 2010)

Figure (3-5) illustrates the use of a box-plot graph to visualise on-time performance data. The names of bus stops are represented on the x-axis while the departure times in seconds are represented on the y-axis. Various visual tools ranging from graphical views to 3D-animation and virtual reality have been used by transit agencies for better managing and the planning of transit operations. Information graphics in the form of charts are typically used to convey information about a single attribute measured at regular time intervals. Most map-based transit applications focus on a particular aspect of a transit service occurring within a geographic space at a single point in time. Transit operators need to visualise their transit fleet performance to monitor and detect any negative service symptoms such as schedule/headway deviation and bus bunching. (Thomas J, 2007) developed new analysis and visualisation techniques for presenting important information to decision makers. The author stated that the visualisation of bus transit performance information was not exploited enough. Efforts to make use of transit data have often been hampered by problems with data collection and post processing as well as budget limitations.

Visualisation techniques such as time-distance diagrams (K., Kuhn, 2011) have been used as a tool to visualise transit performance information. Time-distance diagrams are used to show transit vehicle locations as a function of time. Mapping of quantities as shown in Figure (3-6) is one commonly used method in the transit sector for visualising transit data.

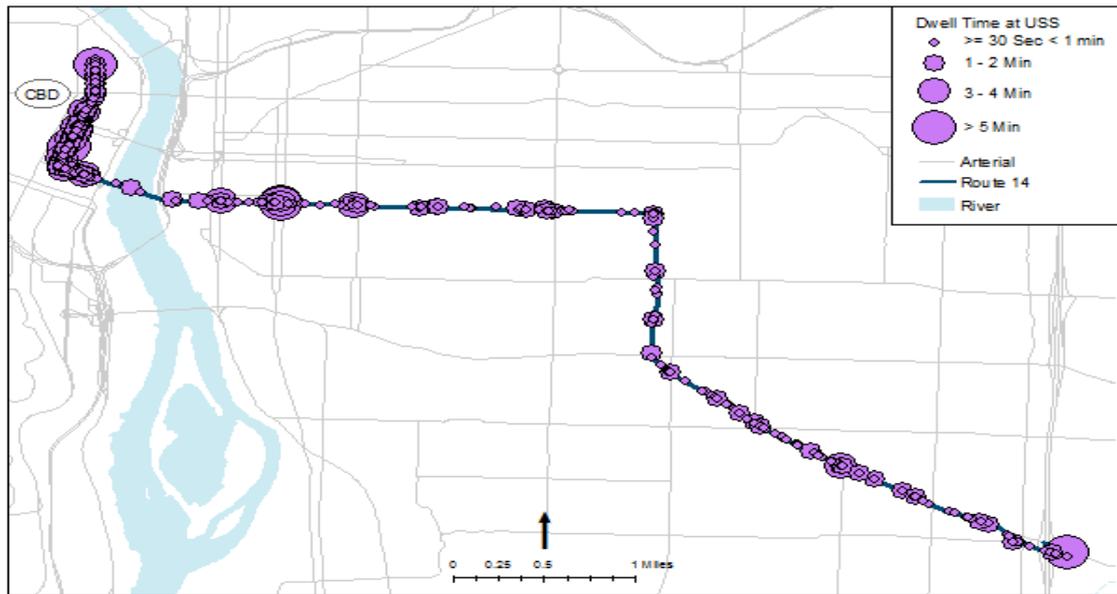


Figure 3-6 The Mapping of Quantities method for transit data visualisation (Source: Thomas J., 2007)

This method basically renders the quantities of an attribute by varying its symbology; either by colour-coding graduated symbols or by using proportional symbols or dot density. As can see in Figure (3-6) dwell time values for each bus stop are rendered by different sized circles.

Linear referencing (Figure 3-7) is another method used in the transit sector. It is used in the area of asset management and transit vehicle performance monitoring purposes. In linear referencing visulasation technique the locations of features are identified by a relative measure along a linear element.

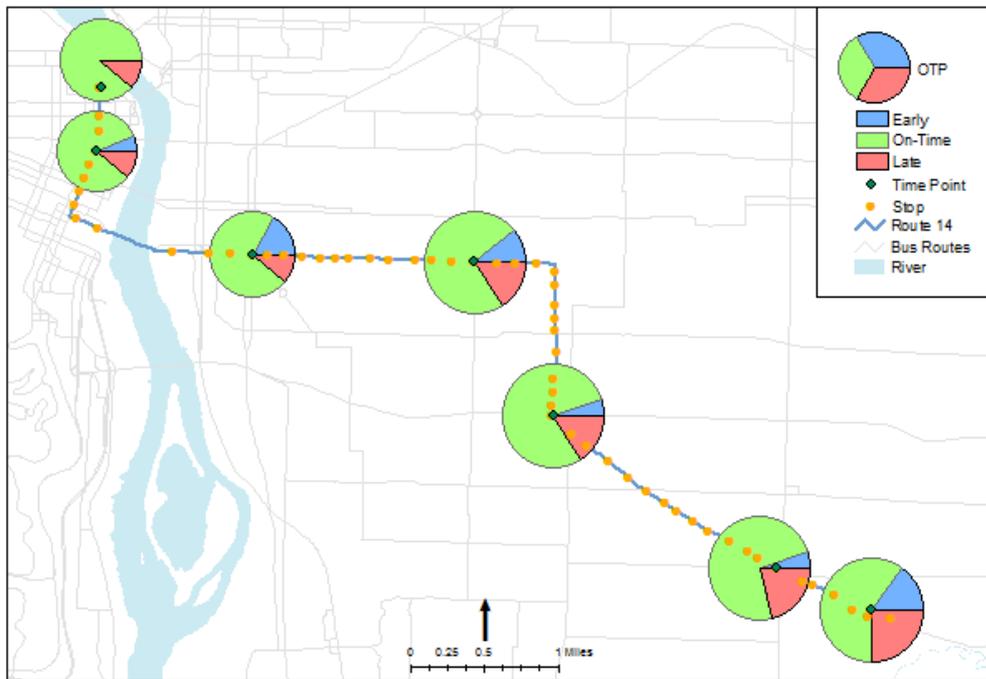


Figure 3-7 Linear referencing method for transit data visualisation (Source: Thomas J., 2007)

As can see in Figure (3-7) bus stop locations are identified by on-time performance values along the bus route.

3-D visualisation is also applicable to visualise transit data (Thomas, J., 2007). It can be used to analyse and display transit performance that cannot be realized in two dimensions alone. In general, visualisation techniques do not create new data, but rather allow attributes inherent in the data to be expressed intuitively. Visualisation techniques can improve the perceived quality of transit data and ease information extraction. For dynamic visualisation, a web-based interface can be considered as one of the main tool which has been used for visualising transit data. With such a tool, transit users are able to see routes, stops and moving buses on digital maps simultaneously. Zoom and pan controls, as well as satellite imagery, allow users to apply their personal knowledge to achieve faster and more accurate transit results. Web-based applications are generally interactive, so users can quickly navigate to a geographic area of interest, (e.g., place of work or home) or view only a specific bus route. (Ricardo H., 2009) developed a web-based application for the public transport system of Calgary, Canada. The application was developed to explore alternative

techniques of schedule dissemination. In this application, Google maps were used to visualise transit information. Figure (3-8) shows a screenshot of the Calgary (Canada) public transport system.

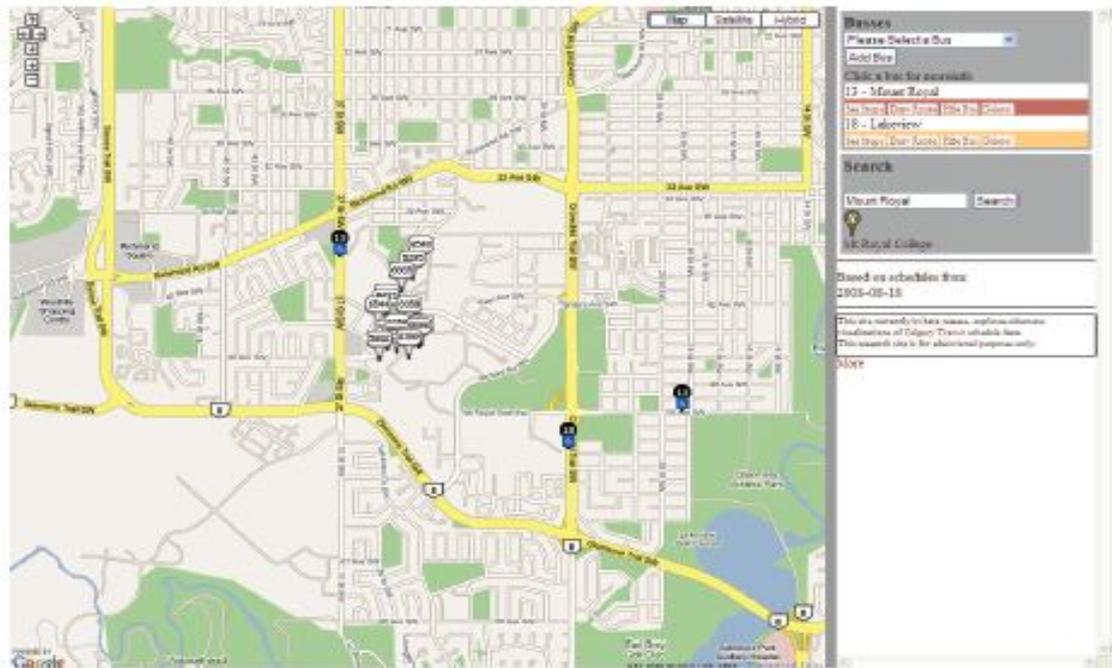


Figure 3-8 Screenshot of Calgary (Canada) public transport system (Source: Ricardo H., 2009)

As we can see in Figure (3-8) which represents a public interface of Calgary Canada public transport system transit vehicle are depicted on transit map and on the right side input box tools is provided for faster transit data retrieval and allow users to select and add particular buses they are interested in. These tools called location search and bus lists. To enhance and improve the usability of a public transport system through visualisation, (B, Ferris, et al., 2011) developed a web-based OneBusAway transport application. The Authors described the application as a set of transit tools focusing on providing real-time information to transit riders in the Puget Sound region of Washington State. Figure (3-9) shows a screenshot of the OneBusAway transport system (Source: B. Ferris. et al., 2010)

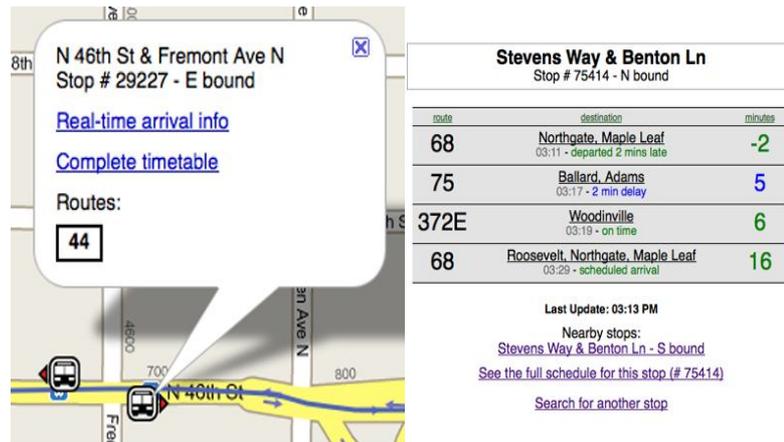


Figure 3-9 A screenshot of OneBusAway transport system (Source: B. Ferris. et al., 2010)

### ***3.6 Bus Arrival/Departure Times Prediction Models***

Walking out of the house on cold and wet winter mornings to catch the bus, knowing with confidence that arrival is imminent, would be a dream for many users of public transport systems. One of the most important pieces of information for transit users is bus arrival times to a particular location. The provision of timely and accurate transit arrival/departure time information would help passenger decision-making and reduce waiting times. The availability of bus arrival/departure time information can enhance the credibility of transport systems, attract additional ridership and increase the satisfaction of transit users (Caulfield, B. and O'Mahony, 2007).

Arrival time deviation of buses is usually caused by several stochastic and hard-to-predict factors such as traffic congestion, ridership distribution and weather conditions. These factors fluctuate spatially and temporally, which makes developing vehicle arrival prediction models a challenging task. The resulting effect of these factors on transit systems includes increased passenger waiting times, bunching between pairs of transit vehicles, variance from schedule/headway adherence, increasing the cost of operations, traffic delays, etc. These factors can reduce the level of transit service and discourage people from using the transit system.

One way to attract people to use transit systems is to provide accurate prediction of vehicle arrival/departure time and expected delays through a 'Passengers Information System' (Caulfield, B. and O'Mahony, 2007). Predicted bus

Arrival/departure times can be made available to the public and displayed via mobile, web, LCD and LED monitors, to passengers who are en route, on-board, or at-station. Figure (3-10) shows an example of the Dublin Bus displaying bus arrival times at a bus stop (Data Display, 2012).



Figure 3-10 Displaying bus arrival times at a bus stop

A review of the literature shows that some prediction models work better for long-term predictions, while others are only suitable for short-term predictions. Some models are statistical/mathematical models while others are more sophisticated, including Kalman filter models, artificial neural networks and machine learning algorithms (Bratislav et al., (2007; Shalaby, and Farhan, 2004; Ding, Y., and Chien 2002; Bin, and Baozhen, 2006; Zheng et al., 2006). Dynamic transit data sources such as GPS/AVL, APC, magnetic ticket data and others are used as the main sources of real-time input for the prediction models. In general, prediction models can be classified into five categories (Gurmu Z., K., 2010; Padmanaban, R. et al, 2009)

- Historical data-based models
- Time series models
- Regression models
- Kalman filtering models
- Machine learning models

### *3.6.1 Historical Data-Based Models*

A variety of versions of historical models have been developed for prediction of bus arrival times: they are broadly classified into models that use average travel time and models that use average speed. Historical models predict travel time for a given time period using the average or median for the same time obtained from a historical database. These models assume that traffic patterns are cyclical and the relationship of historical travel time to current travel time reported in real-time will remain constant. (Williams, B. and Hoel, L. 2003) stated that traffic conditions normally follow consistent daily and weekly patterns, leading to an expectation that historical averages of the conditions at a particular time and day of the week will provide a reasonable forecast of future conditions at the same time of day and day of the week. Therefore, these models are reliable only when traffic patterns in the transit area are stable. Historical models require an extensive set of historical data to produce reasonable results.

(Lin, W.H. and Zeng, J. 1999) Conducted a study in a rural area to develop four algorithms to predict bus arrival times using GPS data. The simplest algorithm used only the real-time GPS data, whereas other algorithms used information including schedule information, the difference between scheduled and actual arrival, and waiting time at check-stops and bus locations. The authors claimed that their algorithms outperformed several existing algorithms and that their algorithm utilizing all four inputs showed the best performance.

(Jeong, R., and Rilett. L. 2004; Ramakrishna Y et al., 2006) have shown that the historical data-based model outperformed some other models. (e.g. multiple linear regression models). A model for the expected time of arrival (ETA) was developed by (Chung E.-H. and Shalaby. A, 2007) for school bus services. This model uses two inputs: the last several days' historical data and the current day's conditional operations. The authors evaluated the performance of the proposed model using data collected from real-world operations of school buses. It was found that the proposed model showed lower prediction error than did the moving average and regression models.

### *3.6.2 Time Series Models*

Time series models assume that the historical traffic patterns will remain the same in the future. The accuracy of time series models is a function of the similarity between real-time and historical traffic patterns (Chien, S.I.J, et al., 2002). Variations in historical data or changes in the relationship between historical data and real-time data could significantly impact inaccuracy in the prediction results. Angelo, (M.P, et al., 1999) used a non-linear time series model to predict a corridor travel time on a highway. The author compared two cases: the first model used only speed data as a variable, while the second model used speed, occupancy and volume data to predict travel time. It was found that the single variable model using speed was better than the multivariable prediction model. These models have been claimed to be effective for link travel time and traffic volume prediction either alone or in combination with other models (Al-Deek, et al. 1998; Thomas, et al., 2010).

### *3.6.3 Regression Models*

Regression models are a conventional approach for predicting travel time. These models predict a dependent variable with a mathematical function formed by a set of independent variables (45). To establish a regression model, the dependent variables need to be uncorrelated. This requirement limits the applicability of these models to transportation because variables in transport systems are highly inter-correlated (Chien, S.I.J, et al., 2002). (Patnaik.J et al., 2004) proposed a set of multiple linear regression models to estimate bus arrival time using data collected by automatic passenger counters (APC). The authors used number of stops, distance, dwell times, boarding and alighting passengers and weather descriptors as independent variables. The authors indicate that the proposed models could be used to estimate bus arrival time at subsequent bus stops. One advantage of multiple linear regression models is that they reveal which inputs are more or less important for prediction. For example, (Ramakrishna Y et al., 2006) found that bus stop dwell time from the origin of the route to the current bus stop and intersection delay times from the origin of the route to the current bus stop are less important input for the prediction model.

### *3.6.4 Kalman Filtering Models*

Kalman filtering models have been widely used in travel time prediction research (Vanajakshi, et al., 2009; Chen, et al., 2004; Wall, et al., 1999; Chien, S.I.J, et al., 2002). These models have the potential to adapt to traffic fluctuation with time-dependent parameters (e.g. filter gain). These models are effective in predicting travel time one or two time periods ahead, but they deteriorate with multiple time steps. (Wall, et al., 1999; Yang, J.-S, 2005) developed a transit vehicle arrival time prediction algorithm by combining real-time AVL data with historical data. Their algorithm consists of two components: tracking and prediction. They used a Kalman filter model to track vehicle location and statistical estimation for the prediction of bus arrival times. Empirical results showed that the proposed model was able to produce predictions that could be beneficial to transit users. (Shalaby, and Farhan, 2004) developed a bus travel time prediction model using Kalman filtering. They used data from buses equipped with AVL and APC systems. Compared to other models, the authors claimed that Kalman filtering outperformed the historical model, regression model and time lag recurrent neural network models in term of accuracy. (Vanajakshi et al., 2009) developed an algorithm based on Kalman filtering under heterogeneous traffic conditions on urban roadways in the city of Chennai, India. The results obtained from the study were promising, with their algorithm outperforming the average approach. In general, it appears that Kalman filtering algorithms give good results for dynamic travel time estimation.

### *3.6.5 Machine Learning Models*

Machine learning models have some advantages compared to statistical models. They have the ability to deal with complex relationships between predictors that can arise with large amounts of data. These models can also deal with non-linear relationships between predictors and are able to process complex and noise data. They are location-specific solutions, requiring significant efforts in input and model selection for each specific application, via correlation analysis, genetic algorithms or trial-and-error procedures (Recknagel, F. 2001).

Support Vector Machines (SVMs) are a set of related supervised learning methods used for classification and regression. SVMs have shown some success in time-series analysis and statistical learning. (Chun-Hsin et al., 2003; Bin, Y. Z., et al., 2006)

proposed the Support Vector Machine (SVM) as a new neural network algorithm to predict bus arrival time. They developed the SVM model to predict arrival time based on the travel time of a current segment and the most recent travel time of the next segment. The model was tested using off-line data of a transit route and exhibited advantages over Artificial Neural Networks (ANN).

Due to their ability to solve non-linear relationships, ANN have been widely used in predicting bus arrival. ANN are motivated by emulating the intelligent data processing ability of human brains, and are constructed with multiple layers of processing units. ANN models have proven to be effective for the provision of satisfactory bus arrival times information. They could be very useful in prediction when it is difficult or even impossible to mathematically formulate the relationship between the input and output. Though the learning and testing process is inherently delicate and is slow to converge to the optimal solution (Hagan, et al., 1996), it is still possible to do off-line training and adapt ANN to real-time conditions if the inputs are chosen carefully. (Chien, S.I.J, et al., 2002) developed an enhanced ANN model to predict dynamic bus times using a Back-Propagation algorithm. The authors claimed that their model could perform accurately for single and multiple stops. (Chen, et al., 2004) developed a methodology for predicting bus arrival times. Their model consisted of an ANN and a Kalman filter. The authors indicated that their model performed well in modelling variations in bus-arrival times along the service route. (Ramakrishna Y et al., 2006) developed a Multiple Linear Regression (MLR) model and an Artificial Neural Network (ANN) model for the prediction of bus travel times using GPS-based data. These models were applied to a case study in Chennai city, India. The Author indicated that the Artificial Neural Network model performed better than the Multiple Linear Regression model.

In summary, collection of data for prediction models has been made possible using techniques such as AVL (e.g. GPS), and APC. New prediction methods such as map matching and vector support regression models have been shown to give promising results. In areas where there is stable demand and similar traffic patterns, historical based models can give satisfactory bus arrival time information. Many of the studies mentioned above evaluated the performance of their models in terms of accuracy; however, some looked into the robustness and stability of models.

### ***3.7 Transport Systems Reliability Measurement***

The reliability of transit services is important for both the service users and operators in particular. Increased wait times, headway deviation and uncertain arrival times are recognised problems of unreliable transit services for users. Reliability affects the amount of time passengers must wait at a transit stop for a transit vehicle to arrive, as well as the consistency of a passenger's arrival time at a destination from day to day. Reliability encompasses both on-time performance and the regularity of headways between successive transit vehicles. On-time performance indicates the likelihood that buses will be where the schedule says they are supposed to be, when they are supposed to be, give or take a little. It has been a transit industry practice to consider buses on time if they arrive at or depart from a time point within a window of one minute early to five minutes behind schedule (Bates, J. 1986).

When buses operate consistently within this window, transit users can time their arrivals at stops to minimize waiting time, with the confidence that their bus will not have already left and with the reassurance that their wait will not be overly extended by delays (Strathman, J, et al., 1998). If headways are not maintained, bus bunching will occur. With the presence of bus bunching, the aggregate waiting time can be large in situations where headway maintenance is the relevant operation control objective. Transit users plan their arrival at bus stops in situations where headways are moderate-to-long, and thus the on-time performance measure is most appropriate in this context. When headways are short, riders are less likely to plan their arrival. With short headway and transit users arriving randomly in relation to the scheduled service, reliability is best reflected in the transit agency's ability to maintain headway and minimize the typical user's wait for his or her next bus. Consequently, whether or not buses are actually running on schedule in this situation is less important than whether they are running on a regular basis (Abkowitz, M. and John T. 1987; Hundenski, R. 1998).

Transit system reliability measurements provide users with a clear picture of service quality, which can encourage people to use transit services more frequently. Transit service reliability measures also help operators to identify persistent service problems, which leads to improvement. Good reliability measures should be clear, understandable and useful to transit users and operators. Bad reliability measures

may be worse than no measures because they can be misleading and give a falsified view of transit services and they waste valuable resources that might be better used elsewhere.

Another measure of transit services' reliability focuses on run time. Mean run time provides insight into the delays experienced on route, while run time variation is more revealing about the uncertainties that passengers and transit planners face in writing schedules and designing routes. Run time reliability is significant to transit users because it allows them to make better use of their own time. Unreliability in running time can deteriorate transit system reliability by increasing in-vehicle travel time and passengers' waiting time. Knowledge of bus running time variability is important to operators who are interested in developing timetables that guarantee on-time performance and hence minimize operating costs.

### ***3.8 Transit Services Quality Metrics Derived from Reliability Measures***

Public transport systems play an important role in providing mobility to people as they move around their communities. Their usability of transit can be enhanced by providing a reliable service to users and so improving the Quality of Service (QoS). QoS indicators are metrics that are used in evaluating public transit performance. These metrics provide transit users and operators with a measure of how reliable the services are and help operators to improve schedule adherence and service efficiency. Similarly, regulatory authorities usually require reporting of QoS metrics to comply with licensing rules and conditions for operating subsidies.

With respect to QoS, frequency of service can be divided into two categories, high and low, depending on the number of vehicles serving an individual route. Low frequency routes are generally defined as those with four or fewer vehicles per hour. It is important for this route type that the service runs exactly to the time specified on the timetable and QoS is specified as the mean deviation of buses from their scheduled time. On high frequency routes (with five or more buses per hour), passengers tend to arrive at stops without consulting a timetable because they expect buses to be running at evenly spaced headways. QoS is measured by calculating the

average Excess Waiting Time (EWT) that passengers have waited above the theoretical waiting time given by the service interval (James G, S., et al, 1998).

### ***3.9 Real-Time Services for Public Transport Software Systems***

Tracking the location of transit vehicles and predicting their arrival at a particular location is a widely-studied problem. However, it is worthwhile to review the research origins of the complexities involved. Tracking systems were first developed for the shipping industry (Ambade S. D. and Shaikh, 2011) where the owners of fleet vehicles often found it difficult to keep track of what was happening. They required some sort of tracking system to determine where each vehicle was at any time and for how long it travelled. Various tracking systems such as signpost, dead reckoning and GPS were used to fulfil these requirements.

For real time tracking, systems are required that can transmit vehicle location along with other information to a central server. One of the first online bus-tracking systems is 'Busview' (Stuart D. M. and Daniel J. D., 2001), developed at the University of Washington. 'Busview' operates one of the largest AVL-enabled fleets of vehicles in the United States. The system delivers real-time transit vehicle information to the travelling public via the Web. 'MyBus' (Stuart D. M. and Daniel J. D., 2000) is an application to make departure predictions and deliver traveller information to web browsers. The goal of the MyBus transport system is to provide transit riders with real-time information on buses at specific locations of the transit region.

(Ricardo, H. 2010) developed a web-based real-time transit system which disseminates transit information through intuitive GIS techniques. In this system, using data from Calgary (Canada) a map-based interface has been created to allow users to see routes, stops and moving buses all at once. 'OneBusAway' (B., Ferris et al 2010) is a transit system designed to enhance the usability of transit systems. The system is a set of innovative transit tools focused on providing real-time arrival information for the Seattle area (US). It provides access to transit information through a variety of interfaces, including web, phone, SMS and mobile devices.

'Wave Transit' (Jason D., et al ,2011) the local bus service provider for Wilmington North Carolina (US), has a system in which the buses send their coordinates to a central database every thirty seconds using AT&T's cellular data service. This data allows the dispatcher to know where all the buses are at any given time. The system provides real time tracking of buses for a public transit authority. Key requirements were the development and display of Expected Arrival Time (EAT) for all buses via mobile, web, LCD and LED displays. The Transit Tracker system from Trimets (Crout DT, 2007) is a real-time customer information system that provides rail and bus arrival estimates via the Internet and mobile phone devices and light-emitting diode (LED) displays at a limited number of rail platforms and bus stops.

'CTA Bus tracker' in Chicago Transit Authority (US) uses GPS technology to report bus location data to a central server where transit users can then see their buses on a map in real time, while the tracker system estimates when they will arrive at bus stops. The 'NextBus' system (NextBus, 2012) uses Satellite GPS technology to deliver real-time transit information to the public via web, mobile phones and SMS services. The system is based on analysis of vehicle position data from a GPS-based AVL system. The transit system estimates vehicle arrivals with a high degree of accuracy and this estimate is updated constantly. In these systems, transit users can share information such as the current state of a bus or train by submitting reports when a bus leaves a stop. These reports allow the system to adjust the expected locations of the bus and publish text reports to mobile users.

A crowd-sourced alternative to official transit tracking was proposed by (Arvind, T, et al., 2010). The system was called 'cooperative transit tracking'. It is proposed as an alternative or complement to official transit tracking. The proposed system enables users to collectively track transit vehicles by reporting their location while inside them. The application remains as a background process after the user is finished with it, waiting to see if the user eventually enters a transit vehicle. Once in a transit vehicle, the phone anonymously uploads its coordinates, contributing tracking data to a central server. A system for bus arrival time prediction and associated traveller time information is presented by (Kavoussanos M. and Daskalakis K., 2004). The system provides bus location information, traffic information and bus arrival time predictions.

To investigate the usability of crowd-sourcing social computing systems in the transportation industry, the 'Tiramisu' transit information system was developed by (John Z. et al., 2011). In this system, commuters share GPS traces and submit problem reports. 'Tiramisu' processes incoming traces and generates real-time arrival time predictions for buses. To reduce the cost and complexity of offering a full transit tracking system, including complete and accurate digital route maps, in-vehicle-devices and on-line tracking websites, a smartphone-based bus tracking system called 'EasyTracker' was created (James B., et al., 2011). The system was created as an automatic system for transit tracking, mapping and arrival time prediction. The authors claim that the system provides accurate transit tracking and real-time travel time prediction, all without manual interaction.

Based on an analysis requirement of function for public transport vehicle location and navigation system (Gong Liang and Qiang, 2006), presented a vehicle navigation system using a GPRS communications platform. The authors stated that the system can be used not only for vehicle location and dynamic navigation but can also provide safety and security for vehicles and various information for drivers. A system (TransDB) that covers the development of methods for GPS data management with applications in collective transport was presented in (Christian S., and Dalia T. 2008). The study focused on bus travel time prediction and the communication between the vehicles and their surrounding infrastructure. The Authors describe the system as a dynamic, integrated system for managing position-related data of vehicles traveling along pre-defined routes and expect that the proposed methods will be robust and adapt to changes in the environment.

### *3.9.1 Real-Time Transit Information for Trip Planning Services*

Transit systems provide passengers with information to assist in making travel decisions prior to their departure and/or during their trip. Pre-trip information includes schedules, routes and estimated times of arrival/departure. The access mechanisms of pre-trip information can be land line telephones, websites, wireless devices and display boards. Recently, transit agencies have made their service information available on the Internet, using maps, schedules and on-line automated trip planners. A journey by bus is usually part of a longer door-to-door itinerary,

usually involving walking before, after or between bus segments. Transit users are interested in door-to-door journey times when making decisions about time of departure and which bus to catch.

An extensive literature review shows that many software applications have been developed to help passengers to manage their time and have good journeys. (Christopher C. et al., 2006) developed a prototype of a trip planner that could be implemented by transit agencies. The authors highlight issues related to designing trip planner software, such as software performance and user features. This system provides users with transit information such as the bus number they should take to reach their destination as well as the optimum path between the origin and destination points. The output of this system is presented to the user both in text and on a map. Figure (3-11) shows an example of trip planner of Calgary Canada public transport system.

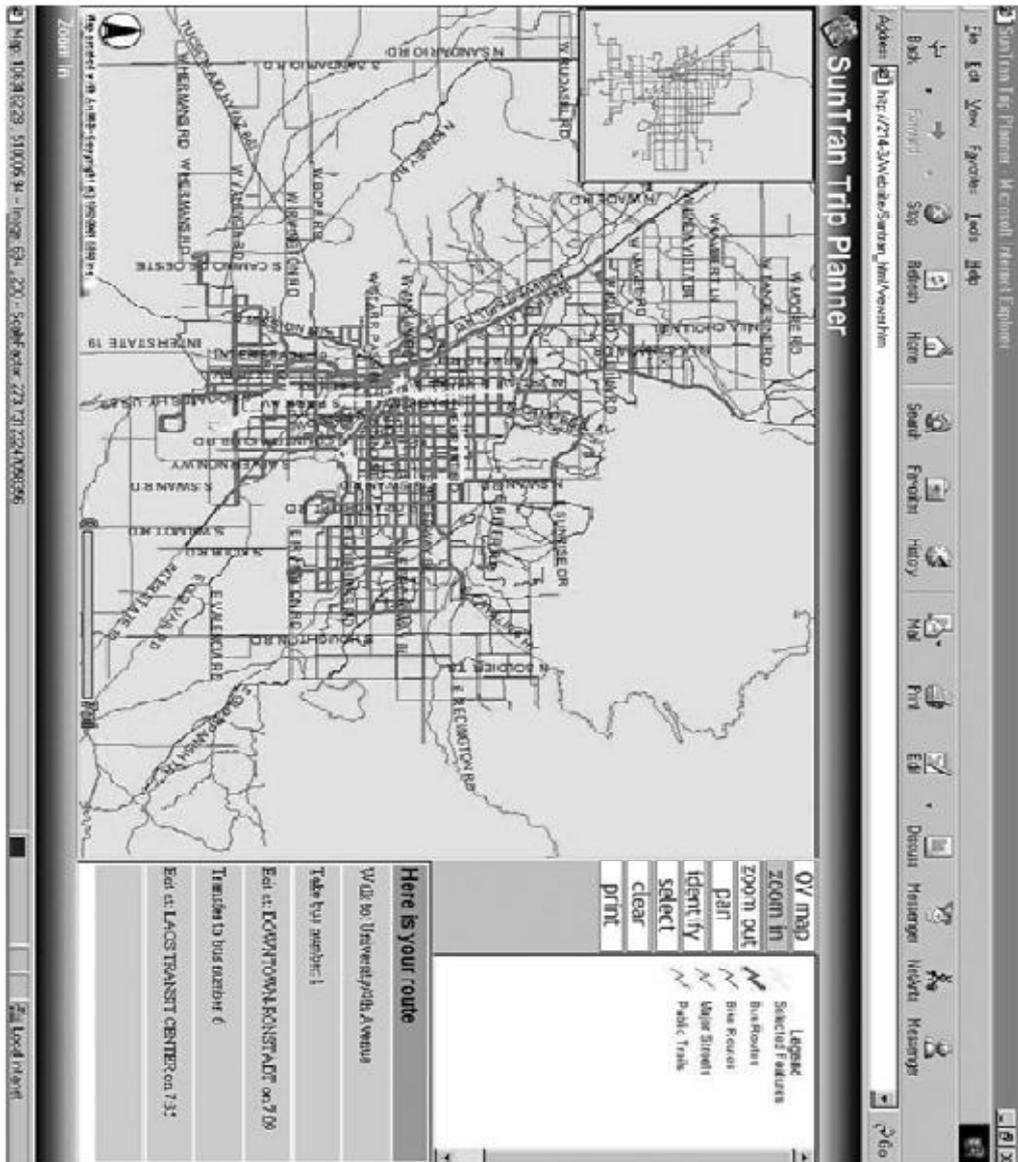


Figure 3-11 Screenshot of trip planner of Calgary Canada public transport system  
(Source: Christopher C. et al., 2006)

(Jerald J et al., 2010) is a transit trip planner (TTP) system from the University of California, Berkeley. The system predicts the shortest paths between any two points within the transit network using real-time information provided by a third party bus arrival prediction system, which relies on GPS-equipped transit vehicles. In the proposed system, users submit their origin and destination points through a standard web browser or map-based mobile device. A server implementing dynamic K-shortest paths algorithms with predicated link travel times returns personalized route directions for the user, displayed on a map. Transit services such as 511.org

(511.org, 2012) and Google Transit (Google Transit, 2012) allow users to plan public transit trips by generating routes based on static schedule data.

(Jing-Quan Li, et al., 2010) have developed a multimodal trip planning system that provides a park-and-ride travel mode and incorporates real-time traffic and transit information. The overall system consists of a trip planning server, web and cell-based clients, transit vehicles, arrival time estimations, customized sub-system modifications and a database. The authors claim that the preliminary case studies show that the multimodal trip planning system works very well.

Journey planner systems such as (JustRoutes.com, 2012), offer transit information as well as the best routes between two selected points to get around Dublin city (Ireland). Users can either enter start and ending addresses, or can click on two different spots on the map to get the distance between the two points and the best routes in which to travel between them. Figure (3-12) shows the public interface of the JustRoutes trip planning system.

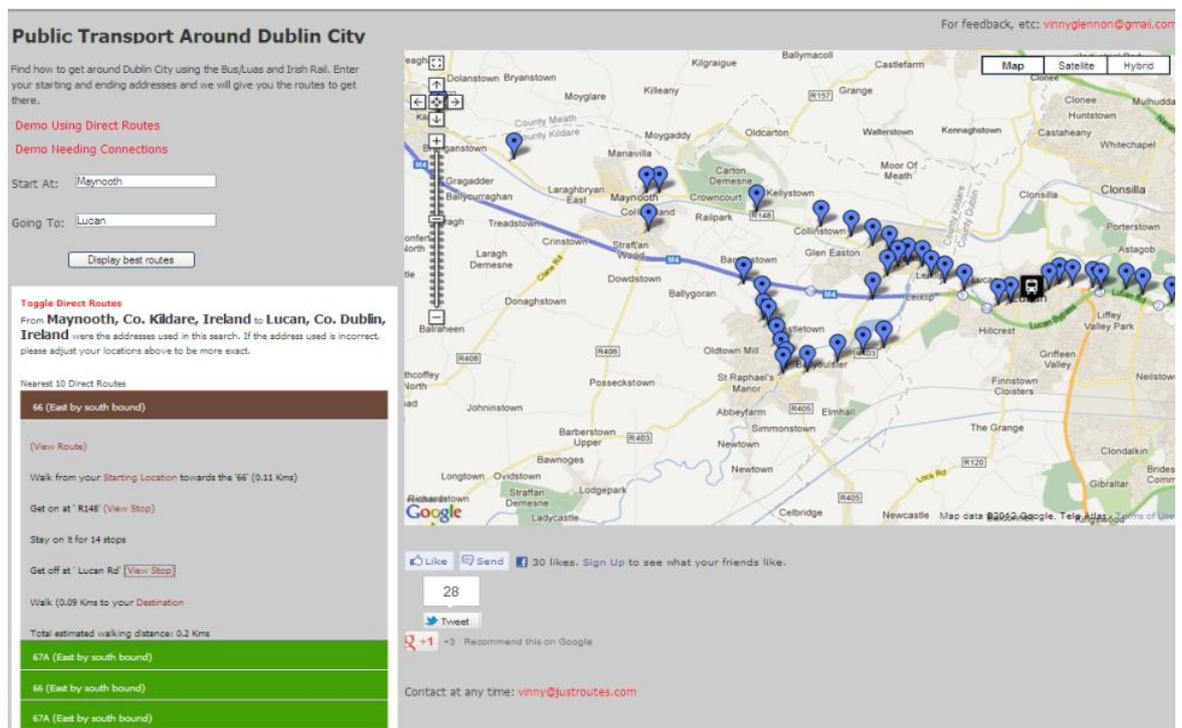


Figure 3-12 Public interface of Just Routes trip planning system (Source: <http://justroutes.com/>, 2012)

### *3.9.2 Mobile Applications for Public Transportation Systems*

Real-time transit information for buses, subways, light rail and other transit vehicles are displayed in a significant number of cities worldwide at places such as rail stations, transit centres and major bus stops. With the possibility that real-time transit information will not be available on a public display at every stop, mobile devices are used to help manage the complexity of using transit information. Whether it is a simple phone or SMS interface or a more complex native mobile application, these systems can provide schedules, routes and real-time arrival/departure information. Google Transit, which was started as a Google Labs project in December 2005, is now directly integrated into the Google Maps product and provides interfaces to Google Transit on a variety of mobile devices, making use of location sensors such as GPS and WiFi localization on the device to improve the usability of the transit application. Various other mobile-phone-based transit information systems have been developed to provide users with transit information. The Intelligent Transportation System research group at the University of Washington has developed a real time-system for predicting bus-arrival time, based on access to transit agency data. The prediction times are made available to the travelling public via a web site known as MyBus (MyBus, (2012)). The usability of public transit systems can be enhanced by providing a good traveller information system.

(B. Ferris., et al., 2010) makes use of the increased availability of powerful mobile devices and the possibility of displaying transit data in machine readable format. The system delivers transit information such as bus arrival times on internet-enabled mobile devices. (Stuart D. M., Daniel J. D. 2001) have designed a real-time transit information system to deliver transit information to internet-enabled mobile devices such as cell phones. The content is in the form of arrival/departure times for buses at user-selectable geographic locations within a transit region. The authors indicate that the physical restrictions of mobile devices, such as screen size and paucity of keyboard options was overcome through considered user interface design.

(Bertolotto, M et al. 2002) describe the BusCatcher system. The main functionality provided includes a map display with overlaid route plotting, user and bus locations, bus timetables and arrival times. (Barbeau, S.J et al., 2010) describes the Travel Assistance Device (TAD), which aids transit riders with special needs in using

public transportation. (Turunen M., et al., 2006) presents approaches for mobile public transport information services such as route guidance and push timetables using speech-based feedback. (Bantre, M., et al., 2004) describe an application called UbiBus, which is used to help blind or visually impaired people to take public transport. This system allows the user to request in advance the bus of his choice to stop, and to be alerted when the right bus has arrived.

Through this review of techniques and methods used in public transport systems, it can be seen that many facilities are provided by public transport systems to improve transit services and attract people to use public transport. These facilities include providing real-time information, trip planning services and receiving transit information on mobile devices. The list below summarizes the common facilities provided by public transport systems:

1. Tracking the location of vehicles. In addition to other measurable information (passengers no, vehicle data etc)
2. Communicating transit data to a back-end central server through a variety of wireless communication techniques such as, Short Messages Services (SMS), General Packet Radio Service (GPRS), Radio Communication or Satellite Communication.
3. Providing transit operators with transit data to help measure, analyse and evaluate system performance.
4. Providing passengers with real-time information related to the current location of transit vehicles and the estimated arrival times as well as pre-trip information.
5. Delivering transit information on mobile devices.

The transit services provided by these systems can improve transit services and provide a clear view of the needs of passengers and what should be an ideal public transport system. The high cost of the development of effective systems that meet the needs of passengers, transit operators and regulators alike may be one of the

obstacles that limit the improvement of public transport services. Transit systems work in a stochastic environment where deviation from schedules are unavoidable leading to decrease on quality of service therefore tools are required to improve transit data visualisation for displaying transit information or system performance evaluation purposes. Interaction with transit systems need to be improved through more informative web-based or mobile-based interfaces. Passengers need tools to navigate a transit system in real-time with up-to-date transit information to save their waiting time. Most public transport applications focus more on the needs of the passengers and to a less extent on the requirements of the operators and the regulators. Developing a comprehensive system that takes into account the requirements of all stakeholders may contribute to the improvement in transport services. To summarise and compare our system to various public transport systems we introduce table 3-1 which includes some key features of modern public transport systems.

Table 3-1 A comparison between transport systems and our proposed system

Feature	Transport system					
	NextBus	MyBus	OneBusAway	BusView/Transit Watch	Our system	
Real-time Information	✓	✓	✓	✓	✓	
Web-based Info.	✓	✓	✓	✓	✓	
Mobile-based Info.	✓	✓	✓	✗	✓	
Real-time Timp Planning	✗	✗	✓	✗	✓	
Measuring Performance metrics	✓	✗	✗	✓	✓	
High cost	✓	-	-	-	✗	
Samrt-Phone Interaction	✗	✗	✓	✗	✓	

Table 3-1 indicates that we provide a range of key features of the public transport systems in a single system at a low-cost.

Through this research, we will introduce many improvements in the field of public transport systems by proposing various methods and techniques. We will address how to employ integrated technologies such as computer technology, communication technology and geo-positioning to develop a cost-effective public transport software

system. We will also discuss issues related to the transit data visualisation and propose new methods to visualise transit data. We will address the automation process of measuring public transport system reliability and Quality of Service. We will discuss ways to deliver information to the passengers via web-based interfaces and mobile devices taking advantage of Location Based Service and integrated technologies such as haptic feedback.

### ***3.10 Conclusion***

In this chapter, we have reviewed the techniques and methods used in public transport systems. Having identified the main attributes of a close to ideal public transport software system in Chapter 2 and reviewing the techniques and methods used in public transport systems to provide transit services, we believe that there is still room for research in the development of transport services and the means to provide these services. The next four chapters discuss the implementation of various techniques to develop a public transport software system for monitoring, measuring, visualising and analyzing public transport operations in real-time and off-line environments. Chapter 4 describes a set of tools that can be used by transit operator to measure the quality of service indicators and the reliability of transport system. A description of transit data visualisation will also be included. Chapter 5 introduces models and techniques that enable passengers to easily interact with public transport systems and extract the desired information. Chapter 6 describes the techniques used to tackle the uncertainty issues associated with real-time public transport systems. The development process of bus arrival time prediction models is also described. Chapter 7 describes the design, implementation and overall integration of the public transport software system that can track transit vehicles in real-time and provide passengers and operators with up-to-date transit information. This includes a description of the functionalities of the system components.

# **Chapter 4 Measuring and Visualising Public Transport Quality of Service and Reliability Indicators**

## ***4.1 Introduction***

In Chapter 2 Section (2-2), we discussed most of the attributes of an ideal public transport system, which include the ability to measure and summarise Quality of Service (QoS) and system performance. In this chapter, we explain and describe software tools to measure transit service performance and we also discuss transit services' reliability as well as Quality of Service. We highlight the measurement process of QoS indicators and service reliability using tools designed as a part of this research. Our tools were created for transit operators to visualise and analyse transit data for better QoS measurements and transit service improvement. We make use of original GPS data records to measure and visualise transit system performance. The results will be presented to illustrate the output of the tools. No passenger counts or driver information were available for this study.

## ***4.2 Performance Measures of Public Transport Systems***

Until recently, transit data have generally been collected manually by time-keepers positioned at key points along bus routes. The expensive and time-consuming nature of this process restricts the ability of operators to collect large and meaningful amounts of transit data that could be used to measure and improve transport system reliability (Philip, B. et al, 2005). Performance measures of public transport systems refer to how well the system achieves its intended goals and objectives. They are used to determine how well an agency is adhering to required service standards. Performance measures are required to compare planned (promised) and actual (delivered) levels of service, and are an essential element in characterizing service reliability. These measures are highly flexible in that they can encompass multiple aspects of transit services that are of interest to both agencies and passengers (Thomas J, 2007). They are basically summaries of individual trip outputs (at the

route or time point stop level, for a specified period of time), such as calculated travel time, schedule deviation, headway deviation and passenger loads.

The focus of public transport performance measures has traditionally been on attributes of service supply, such as capacity, passenger loads, frequency, regularity and reliability. However, a number of studies have also focused on performance measures from the demand side. For example, (Kopp, J, et al., 2006) focused on measuring the attractiveness of travel by public transport, while (Ceder, A. et al., 2009) worked on connectivity measures. In (TCRP Report 88, 2003) eight performance measure categories for public transport are defined: 1-availability, 2-service delivery, 3-safety and security, 4-maintenance and construction, 5-economic, 6-community, 7-capacity, and 8-travel time.

### ***4.3 Transit Service Reliability and Its Importance***

Reliability is a key element of any public transport service. Considerable effort is being made by public transport agencies and operators to improve the reliability of their operations and consequently the quality of their services. Improvements in service reliability benefit both users and operators, as less variable services decrease waiting times for passengers and allow for an efficient use of resources by operators. Transit service reliability has been defined in a variety of ways. One of these definitions is “the ability of a transit system to adhere to schedules or maintain regular headway and consistent travel time”. (Turnquist, M. and Blume, S., 1980; Abkowitz, M., 1978) defines reliability as the invariability of transit service attributes that affects the decision of both the users and operators. According to the United States Highway Capacity Manual 2000 (HCM, 2000), there are many measures of reliability used by transit operators. These measures include on-time performance and headway adherence (the evenness of interval between transit vehicles), among others. (Thomas.J.,2001; HCM, 2000) relate reliability to schedule adherence, keeping schedule deviation to a minimum.

On high frequency routes (five buses or more per hour) (Thomas, J. et al., 2000) bus headway is short and passengers are less likely to time their arrival and instead arrive

randomly in relation to the schedule, though a number of studies exist where this restriction is relaxed. For example, in (Bowman, L. and Turnquist M., 1981; Luethi, M. et al., 2006) it was found that some passengers consult the timetables and do not arrive randomly even for five-minute headway services. On high frequency routes, reliability is best reflected in the transit operators' ability to maintain headway regularity and minimize passenger wait time for the next bus. Maintain spacing between vehicles helps to distribute passengers evenly on the vehicles and avoid overloading, which may lead to the accumulation of delays, which in turn results in bus bunching. On low frequency routes (four buses or fewer per hour), bus headway is rather longer and transit users time their arrival to bus stops. Reliability is best reflected in the ability of transit operators to maintain timetable adherence. In this research, we propose appropriate tools to measure transit service reliability when data is available to do so.

All public transport stakeholders have considered the reliability of public transport systems to be critically important. The knowledge gained from reliability measurements with valuable data facilitates the decision-making process to adjust transportation services to needs and requirements (Tyrinopoulos, Y., 2004). The lack of reliability in public transport services results in uncertainty and delays, aggravating anxiety and discomfort for passengers, which leads to increased costs due to lost mileage and lower fleet utilisation for operators. Attitudinal surveys have shown reliability to be among the most important public transport service attributes for all passengers under certain conditions (Abkowitz, M., (1978).

In this study, reliability was considered more important than average travel time and costs. Moreover, unreliable services lead to higher operating costs for the operator, as well as decreased ridership by dissatisfied users. Measuring (QoS) indices and transit services reliability is important to provide an overview of how well or how badly a transport system is working. Improvements in reliability of public transport systems have the potential to enhance the mobility of public transport users and induce car users to switch mode. Therefore, by reducing waiting time variability and total travel time variability, the attractiveness of public transport increases.

For passengers, reliability measures of service performance provide passengers with valuable information to become active participants in the transit planning process and decision making process (Nakanishi, Y.J., 1997). Improving transit service reliability can attract further passengers. This fact could resolve many problems (e.g. helping to reduce traffic congestion, air and noise pollution and energy consumption) because individual private transport would be used less. Measuring service reliability justifies the need to identify and develop eloquent measures of reliability in public transport that describe the variability in service and reflect its impacts on both users and operators.

#### ***4.4 Quality of Services (QoS) and Reliability Indicators***

Quality of Services (QoS) as defined by the Transit Capacity and Quality Service Manual (TCQSM) is the overall measured or perceived performance of transit service from the passengers' point of view (TCQSM, 2003). The Quality of Service measure reflects the decision a potential passenger makes whether to use the transit service or not. For a transit operator, it is helpful to evaluate the passenger's perception of the public transport service in order to improve transit services. Measuring the (QoS) and reliability metrics of bus services has traditionally been a difficult and expensive task for the majority of transit service operators worldwide (Kharola, P. and Prakash, D. C. 2003). Quality of Service and reliability indicators deal with the relationship between service delivery, passenger expectations and passenger satisfaction. These indicators address the question: "Does the delivery of the public transportation service meet or exceed passenger expectations?" They have many dimensions and the importance of any single attribute differs from passenger to passenger. However, the attributes of quality include accessibility, availability, reliability, safety and comfort as mentioned in Section (4-2). Certain attributes such as the degree of passenger satisfaction, issues relating to comfort, safety, cleanliness, security, etc. can be measured by conducting surveys among the population. Additionally, the public transport operators will focus on a wider number of features of the system to characterize reliability, such as on-time performance and headway adherence. For the purpose of this research, we focus on providing tools to measure QoS and reliability indicators, Software tools are designed to measure the performance of transport service on a line or time point level. Line-level

performance includes attributes that relate to the performance of the lines/routes and the vehicles that serve them. Terminals and time point-level performance includes attributes related to the execution of the vehicle's schedule and executed headways, as well as additional parameters concerning the time dimension of the services provided at the terminal stations and time points (e.g. excess waiting time, on-time performance, etc).

#### ***4.5 Software Tools for Measuring Public Transport QoS and Reliability Indicators***

In this research, we designed, developed and implemented a real-time public transport software system where we provided transit operators with efficient tools to measure various public transport (QoS) and reliability indicators. Through the next sections we will explain all these tools. In Section 4.6.1 we provide a tool to automate measuring passengers excess waiting time at bus stops. On-time performance as a reliability indicator is measured in Section 4.6.2. Our public transport software system measures bus headway in Section 4.6.3 and in Section 4.6.4 we describe the measurement of buses travel time reliability. Our system provides different tools to visualise transit data statically and dynamically for transit information provision and transit system performance measurements. These tools can be summarised as:

- Transit data visualisation on the map of the transit system
- Visualising transit data for various measures such as Excess Waiting Time (EWT), headway reliability, headway index, on-time performance, schedule adherence, travel time variability, distance-time trajectory and service gap.
- Visualising spatio-temporal behaviour of transit vehicles to detect operational problems such as bus bunching.
- Visualising operational variables such as vehicle speed or passenger's demand.
- Visualising route progress of transit vehicles.

- Reporting transit data in textual and visual format.

Various web-based interfaces are provided to facilitate measuring and evaluating transit system performance and presenting data in graphical and textual format. Our system provides a web-interface designed for transit operators to interact with the transport system in an easy way. Figures (4-1) and Figure (4-2) show examples of the web-interface for the transit operator.

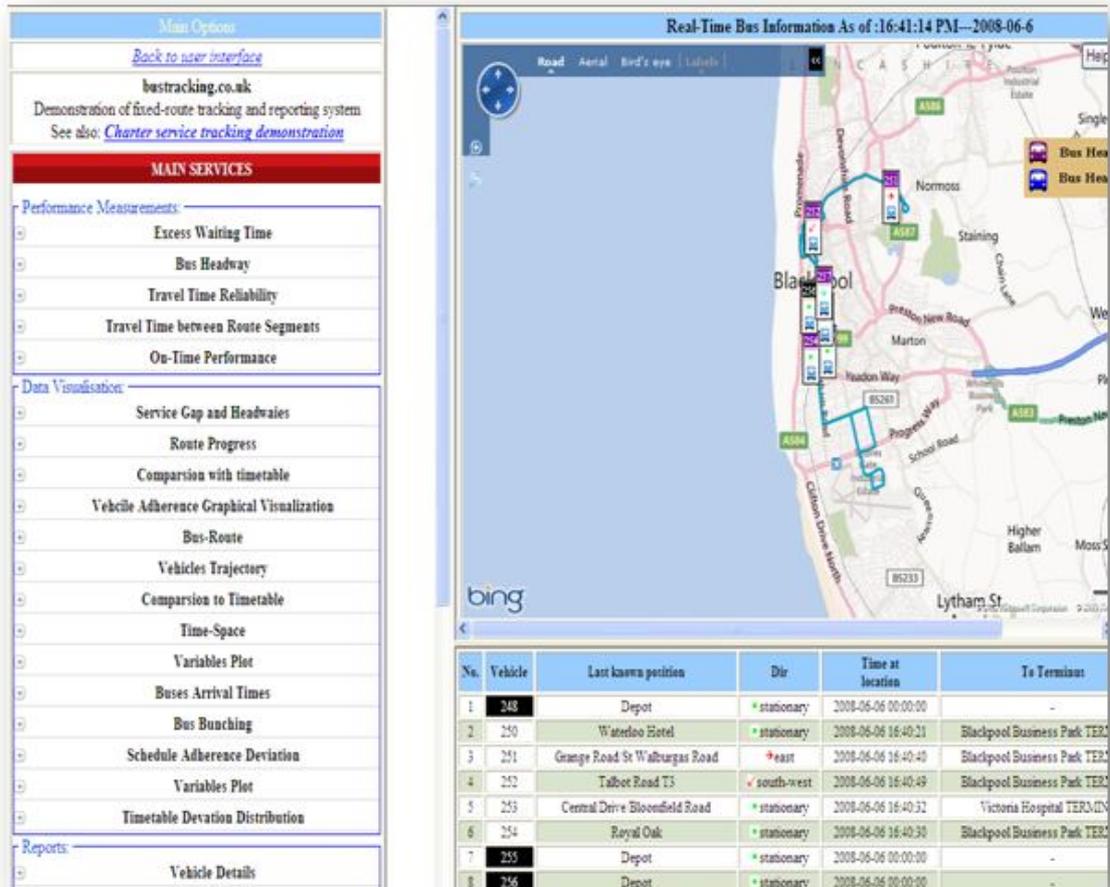


Figure 4-1 Web-interface for the transit operator

As seen from Figure 4-1, on the left of the interface a set of options or programs that enables the operator to measure and monitor the performance of vehicles and display the results on a transit map or in tabular format. In the main window, the transit map appears and icons with vehicle numbers and heading are used to depict the transit

vehicles. A color-code is used to indicate vehicle adherence status to the published timetable. Vehicle data also is shown as a text entry in a table below the map, where vehicle number, the last known position, vehicle direction, date and time at location and vehicle destination are all shown. This information is updated from the transit vehicles at a prescribed interval.

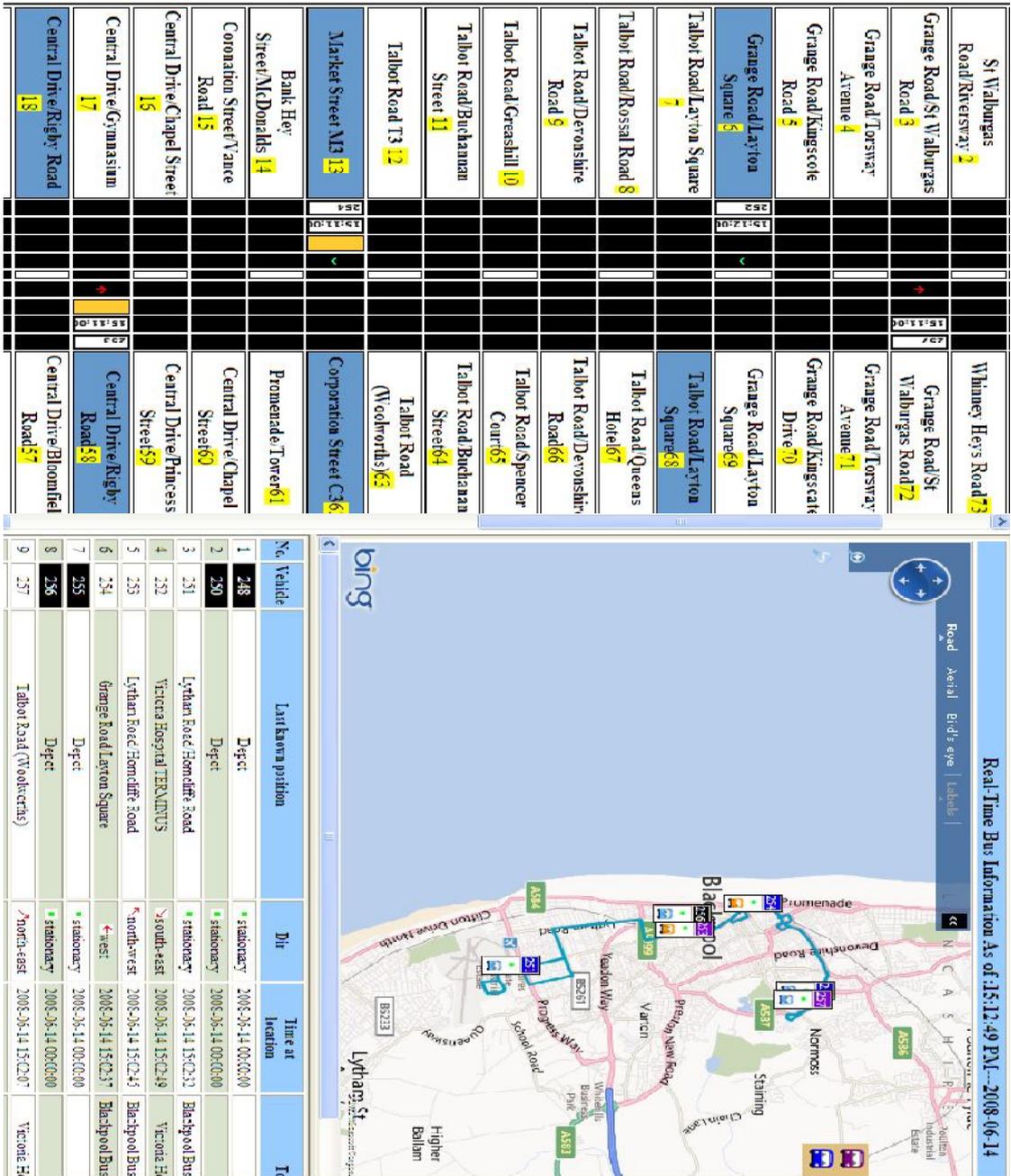


Figure 4-2 Web-interface for transit operator shows bus routes and a set of bus stops. Similarly, Figure 4-2 shows another screenshot of the interface for the transit operator. As we can see on the interface, the left side of the view depicts the bus

route and shows a set of bus stops on both sides of the route. Time points take the blue color to distinguish them from other regular stops. The black colour in the middle represents the road where we can see two vehicles. One vehicle is at “Victoria Hospital (to Blackpool)” which is time point stop and the arrival status is depicted by the amber colour for the early arrival. The other vehicle is in “Corporation Street C3” stop number 62 and its arrival status depicted by the green colour for on time arrival. Another vehicle at Talbot Road T3 stop number 12 and it is an ordinary stop therefore, the vehicle status is not determined.

The ability to dynamically or statically visualise how buses in a route move spatially and temporally is useful for providing transit information and understanding transit information performance. Transit data is displayed on a map as well as in a tabular format. Tools and options shown on the left enable the operator to measure, visualise and analyse transit operations. The tabular format simulates bus routes and shows the current locations of buses, timestamp and bus direction with colour codes indicating their adherence to the timetable. Other options are available on the operator interface for searching for a vehicle/stop on a map or switching between various map views as well as zoom levels.

#### *4.5.1 Measuring Excess Waiting Time (EWT)*

Waiting time at bus stops is one of the most onerous attributes of transit that users experience. Reducing waiting time, especially the component that is most characterised by uncertainty would be of considerable value to passengers. Excess Waiting Time is defined as “the measure of the additional wait experienced by transit users due to irregular spacing of buses or those that failed to run” (London Bus, 2007). EWT, as used by London Buses, is a measure of perceived regularity, measuring the average additional waiting time passengers experience compared to the waiting time they expect. EWT is a standard metric used to measure the quality of services on high frequency routes of public transport systems. The lower the EWT, the more likely it is that passengers will not wait longer than scheduled and will perceive the service as regular, e.g., a 10-min headway route has a scheduled waiting time (SWT) of 5 minutes. A EWT of 1 minute means customers are likely to

wait 6 minutes instead of the expected 5 minutes. (Shalaik, B and Winstanley, A.C, 2009). The greater the EWT value, the less reliable is the transit service.

The advantage of measuring EWT is that it is an objective measurement, easy to understand (expressed in minutes) and it focuses more on the passengers point of view. However, it has disadvantages such as an irregular headway that can affect the results. EWT works best with longer periods of observation, shorter periods can show artificially good results if the last bus in the sample arrives early. The EWT indicator is examined from the perspective of the transit operator and calculated for each line, taking into account the outcome of the operator's scheduling process (scheduled headways) and the actual measurements on site (actual headways). EWT is not designed to be used with irregular scheduled headways. In theory, this could result in a negative EWT score when the service is in fact perfectly regular, and will be zero when the service operates exactly according to the irregular schedule.

Mathematically, EWT can be calculated by subtracting the SWT from the average waiting time (AWT).

$$EWT = AWT - SWT \quad (4-1)$$

$$AWT = \frac{\sum_{i=1}^n AHway}{2 * \sum_{i=1}^n AHway} \quad (4-2)$$

$$SWT = \frac{\sum_{i=1}^n SHway i^2}{\sum_{i=1}^n SHway i^2} \quad (4-3)$$

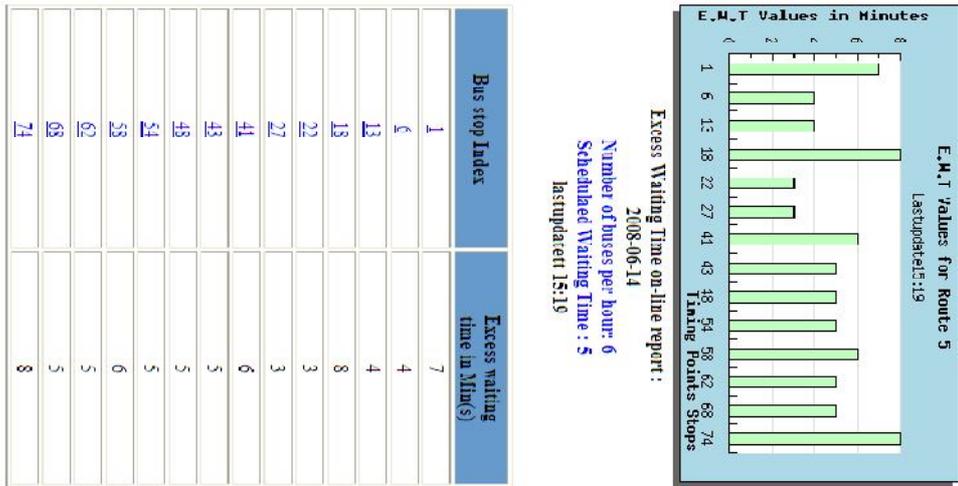
Where:

*AHway* the actual headway

*SHway* the schedules headway

*n* is the no of observations

For example, a ten minutes headway route has a *SWT* of five minutes (i.e. half the headway). For a bus service with a scheduled frequency of 6 buses per hour, the scheduled headway is ten minutes. Average Waiting Time can be calculated by dividing the total of (sum of square of headway/2) over time between 1<sup>st</sup> and last observed bus, then the *EWT* can be calculated by subtracting *SWT* from *AWT* as mentioned in equation (4-1). For example a 4 minutes value of *EWT* means passengers had to wait 4 minutes additional to scheduled waiting time *SWT*. The *EWT* methodology assumes a uniform arrival of passengers. The *EWT* is the only method tested that truly incorporates the experience of all passengers as its output is a result of all data in the dataset. Figure (4-3) presents *EWT* values calculated for bus route 5 of the Blackpool transport system. The *EWT* values are visualised on a map using colour codes for a specific threshold. Values of *EWT* are shown in bar graph as well as in tabular format. On the transit map, *EWT* values are displayed in the icon's pop up window associated with bus stop.



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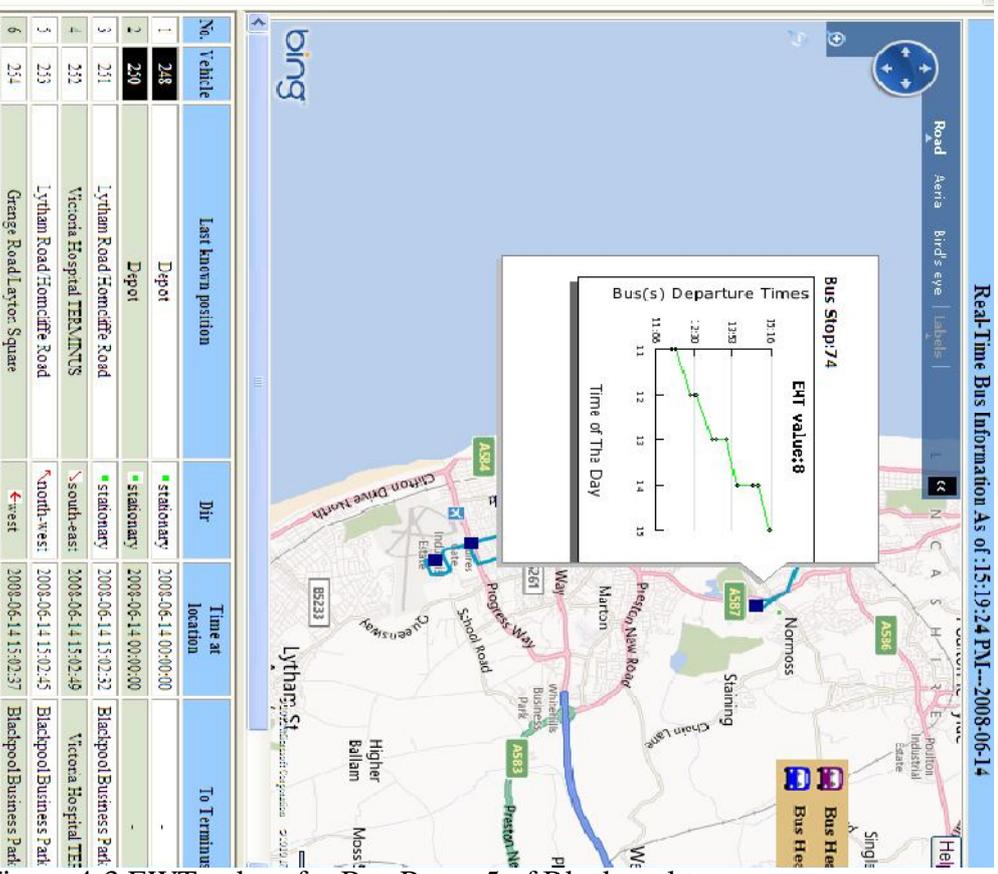


Figure 4-3 EWT values for Bus Route 5 of Blackpool transport system

In Figure 4-3, bus stop numbers can be used as links for detailed information such as bus departure times, actual headways or average waiting times. We note the high values of EWT, indicating irregularities in bus services at the time of measurement.

Excess Waiting Time on-line report :  
 2:06-06-14  
 Stop Index: 6

Bus #	Bus departure time (t)	Headway in minutes (h)	Average wait time for each bus(c)	Weighted A.W.T.
253	11:46	4	2	3
257	11:50	4	2	3
254	12:18	28	14	392
252	12:34	16	8	128
251	12:47	13	6.5	84.5
253	12:58	11	5.5	60.5
253	13:13	15	7.5	112.5
257	13:16	3	1.5	4.5
254	13:46	30	15	450
252	13:58	12	6	72
252	14:07	9	4.5	40.5
251	14:14	7	3.5	24.5
253	14:39	25	12.5	312.5
257	14:51	12	6	72
254	15:24	33	16.5	544.5
252	15:26	2	1	2

Total sum of square headway/2: 2308  
 Time between 1st and last observed bus: 220  
 Average Waiting time in minutes: 10.49(9)9(9)9  
 Scheduling Wasting time in minutes: 5  
 Excess Waiting Time in Minutes: 5

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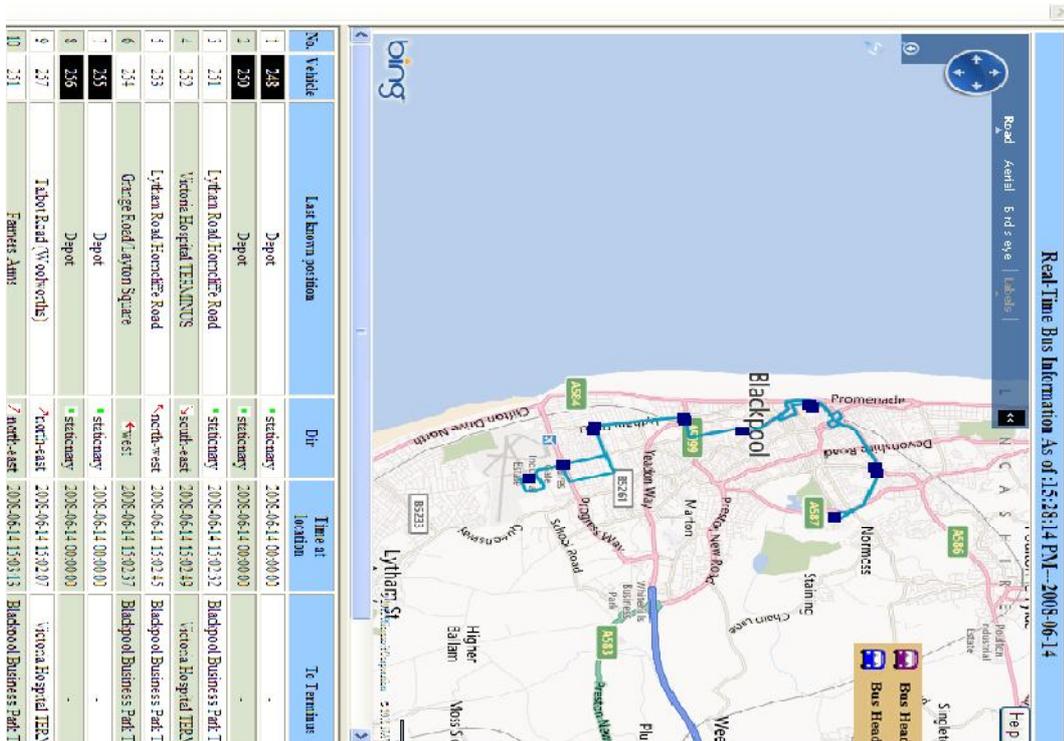


Figure 4-4 Bus departure times and headways for bus stop 6.

As we can see in Figure (4-4), bus departure times and headways for bus stop 6 are shown. The sum of square headway/2 is equal to 2308 minutes, while the time between 1<sup>st</sup> and last observed bus is equal to 220 minutes. The AWT=10.49 minutes. EWT= 10-5=5 minutes.

To help operators to maintain QoS and comply with license rules and conditions, EWT can be measured on daily, weekly or monthly bases. As we see in Figure (4-5), EWT values have been calculated for a month and are shown in both tabular and graphical format. The Table shows the values of EWT calculated for the time points on a particular day from that month.

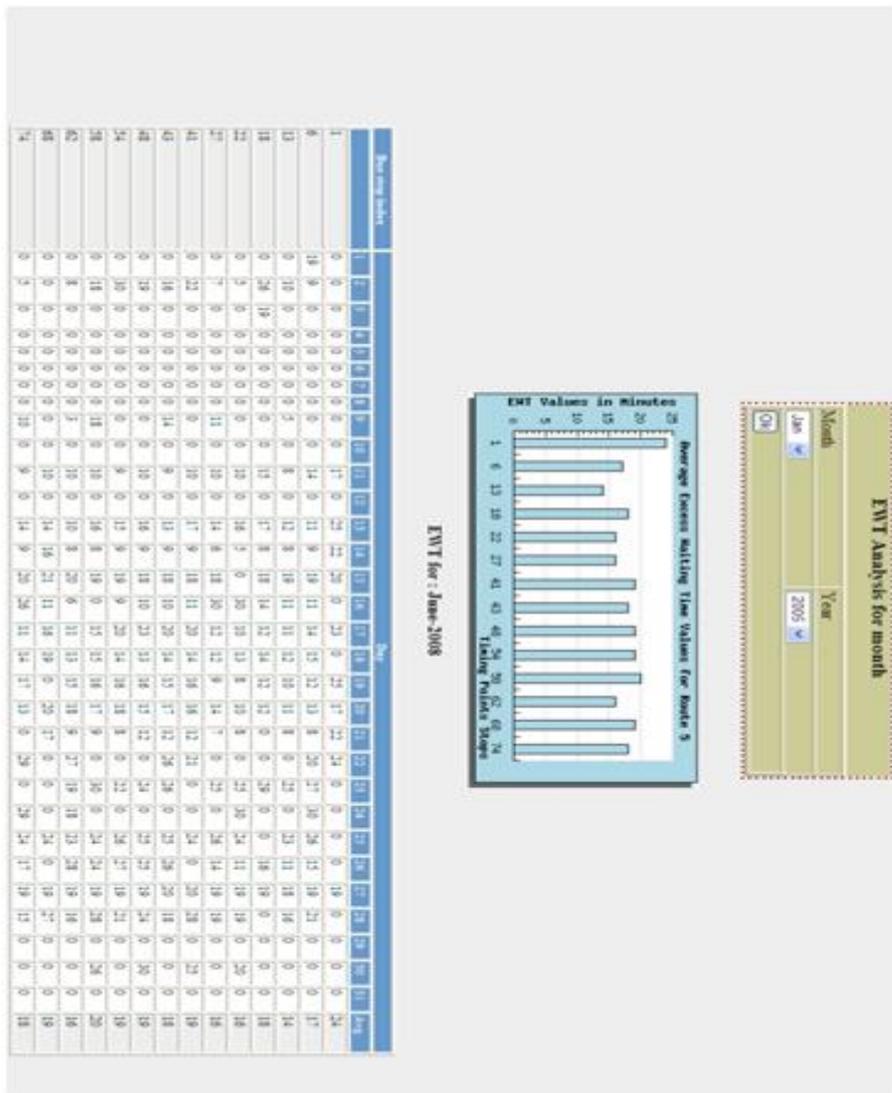


Figure 4-5 EWT values calculated for time points for month

EWT values can be visualised in a way that enables the transit operator to easily detect any irregularity in services. As shown in Figure (4-5) the values of EWT are different and indicate the service regularity or irregularity, for example the value of EWT of stop number 62 in the ninth day of the month is 3 which is an acceptable value for service regularity, while the value of 28 could be considered and shows irregularity in the transit services at that time.

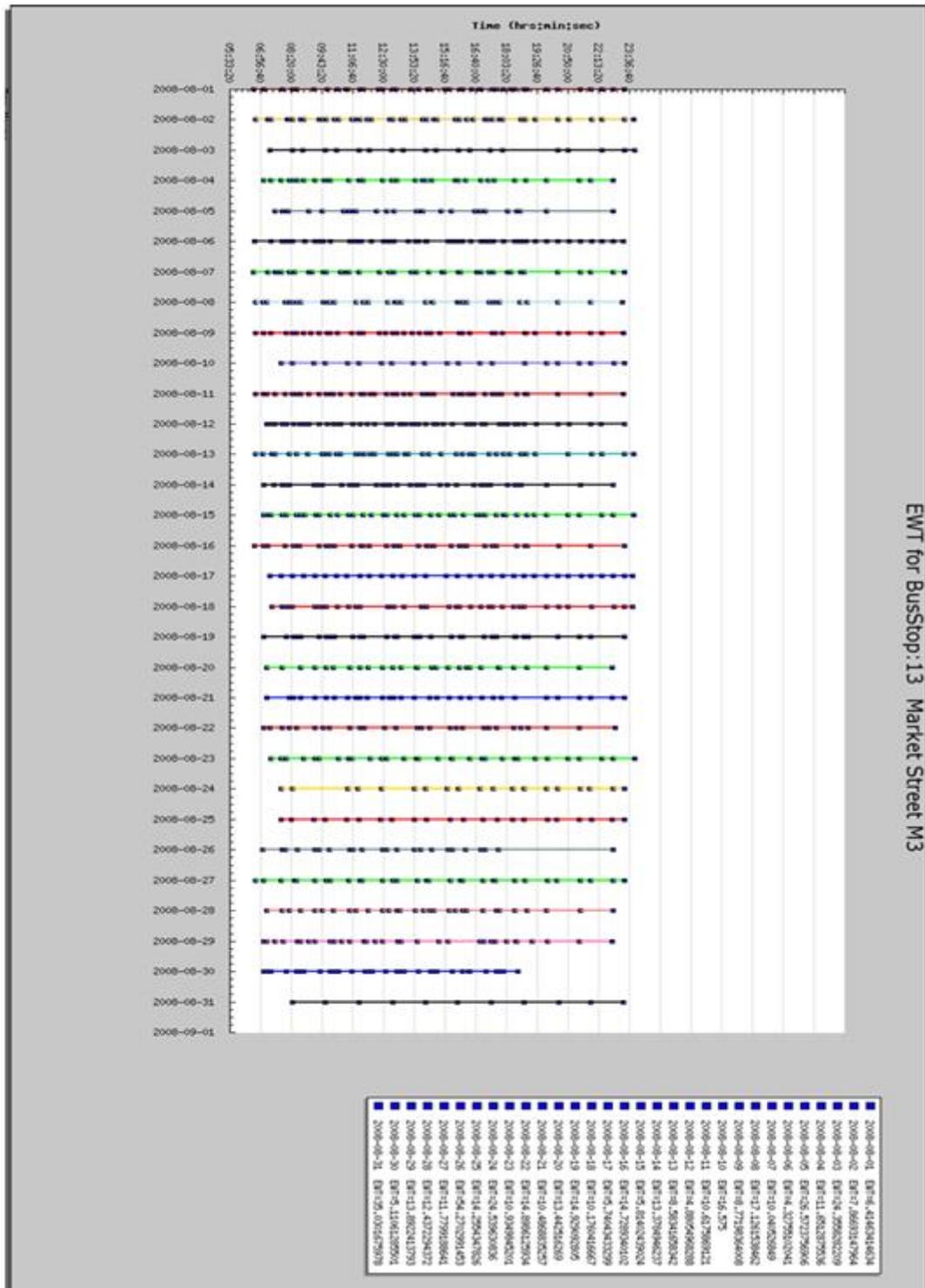


Figure 4-6 EWT values calculated and visualised for a bus stop (13) in a month

In Figure (4-6) the EWT values are calculated and visualised for one month (August 2008). As we can see from the Figure bus departure times are depicted as points on the y-axis where we can see convergence and divergence between these points indicating the regularity in bus services .X-axis, shows date of EWT.

Similarly, EWT is calculated for each time point. Figure (4-7) shows EWT values for fourteen time points calculated at the end of a working day (15-08-2008).



departure times on the y-axis shows convergence and divergence between the services. The representation and calculation of EWT in this way may help to visualise the performance of the transport system and allow operators to detect any bad symptoms of transit service. The purpose always is to help the transportation system operator to manage their transit fleet more effectively, where it is easy to note that any long gap between bus departure times (headways) is an indication of a simultaneous extension of in length of passengers waiting times.

#### *4.5.2 Measuring On-Time Performance Indicator*

In transit industries, there are a number of alternative measures of service reliability (El-Geneidy, A., 2011). These measures can be considered preferable in specific contexts. On-time performance is commonly recognised and employed by transit operators and most widely used as a reliability measure. On-time performance encompasses both headway adherence and missed trips. In transit industry practices, buses are considered to be on time if they arrive or depart a time point within a window of one minute early to five minutes late (Bates, J. 1986; TCRP 10, 1995). On-time performance is the percentage of on-time scheduled trips divided by the total number of scheduled trips available for analysis (Nakanishi, Y.J., 1997). It is a measure of schedule adherence and is used to evaluate system reliability from the perspective of transit operators. This indicator is useful for transit users as well: if buses operate consistently within this window, transit users can time their arrival at stops to minimize waiting time with the confidence that their scheduled bus will not have already left. Many factors can have an impact on on-time performance, including traffic congestion, road accidents, increased ridership, bus bunching and others.

To improve on-time performance reliability, transit operators may need to split a long route into two or more shorter ones, as vehicles on shorter routes are more likely to maintain their schedule. Another approach that could help to keep vehicles adhering to their schedules is to build more time into schedules. In our system for real-time tracking transit vehicles, we provide an easy-to-use tool for measuring and visualising on-time performance values and its distribution at bus stops. Figure (4-8)

shows on-time performance values and their distribution for the fourteen time points and on-time performance indicators visualised on the map. As we can see, in Figure (4-8), on the left the on-time performance distribution is shown in tabular format as a bar graph. On the right, the bus stop “Victoria Hospital” is depicted on the transit map with on-time performance indicators.

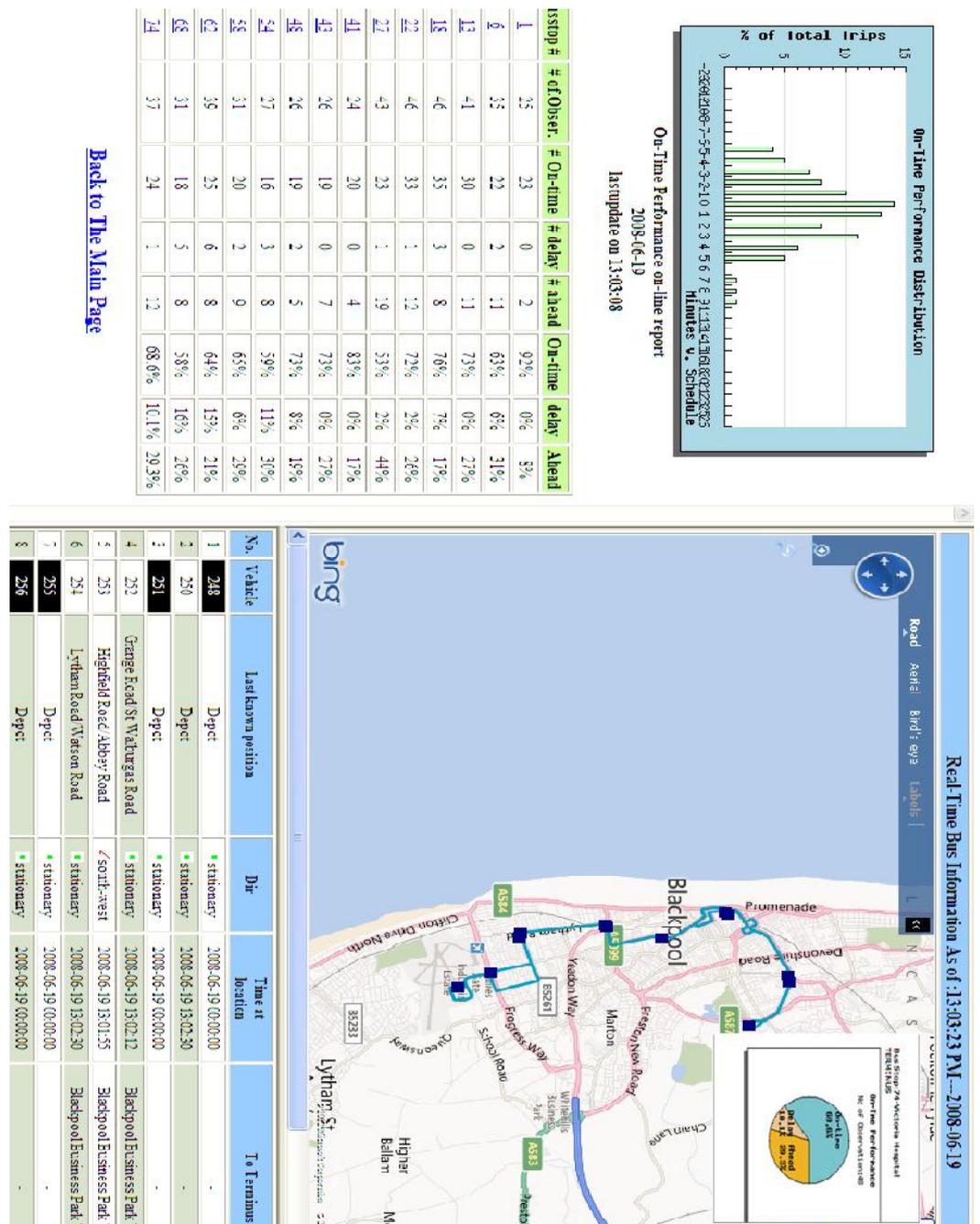


Figure 4-8 On-time performance values and distribution for fourteen timing points

For a more detailed analysis, the system provides detailed reports for every bus stop showing the actual and scheduled departure times and the time difference. Figure (4-9) shows a detailed report of on-time performance for a bus stop. The report indicates the vehicle number, the actual departure time from bus stop, the scheduled time and the difference in minutes.

**On-Time Performance on-line report**  
**2008-06-04**  
**Stopindex 1**

Vehicle	Actual Departure	Scheduled Departure	Time Difference
253	11:44:44	11:40:00	5
257	11:53:01	11:50:00	3
254	12:21:30	12:20:00	2
252	12:33:00	12:30:00	3
251	12:45:08	12:50:00	-5
253	13:11:19	13:10:00	1
257	13:20:17	13:20:00	0
254	13:50:43	13:50:00	1
252	14:04:23	14:00:00	4
251	14:04:45	14:00:00	5
253	14:40:12	14:40:00	0
257	14:50:54	14:50:00	1
254	15:24:36	15:20:00	5
252	15:32:52	15:30:00	3
251	15:42:59	15:40:00	3
253	16:12:26	16:10:00	2
257	16:14:25	16:10:00	4
254	16:54:30	16:50:00	5
251	18:40:18	18:37:00	3
253	19:08:39	19:07:00	2
251	20:09:56	20:07:00	3
251	21:37:41	21:37:00	1
253	22:08:36	22:07:00	2
251	23:31:52	23:37:00	-5
253	23:38:11	23:37:00	1

Number Of Observations:25

On-Time Performance Index:92%

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Figure 4-9 Detailed report for on-time performance for Bus Stop 1

### 4.5.3 Measuring Headway Indicators

In Section 4.5.1 we described the process of measuring Excess Waiting Time that passengers experience as a consequences of unreliable service specifically headway times. In the transit industry, “headway” describes the time between buses or trains on the same line. Headway specifically refers to the time spacing of buses at a particular point, and represents one of the most important transit performance measures. Headway adherence is often used to determine service reliability for high frequency routes, since passengers often arrive randomly and headway irregularity can affect the EWT and passenger loads as headway irregularity is one of the causes of bus bunching which leads to long waiting at bus stops. Service that is not on time affects passengers in terms of increased wait time, travel time uncertainty and a general dissatisfaction with transit system. Passengers are extremely sensitive to wait times at bus stops, so variability of headways causes passengers to perceive a service as unreliable, especially if two or more buses arrive at once after a long gap in service (bus bunching) (Daganzo, F., 2009; Adam M. R, 2008). As we can see from Figure (4-10) the headway concept can be explained on a transit route as a transit route with  $S$  time points which can be accessed by  $n$  vehicles, numbered from 1 to  $n$ . At time  $t$ , the headway  $h_{k,i}^{(t)}$  between vehicles  $k-1$  and  $k$  at station ( $i=1,2,3, \dots n$ ) can be measured as:

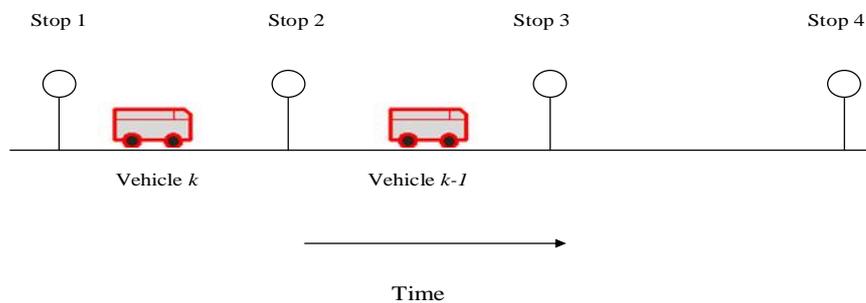


Figure 4-10 Headway concept

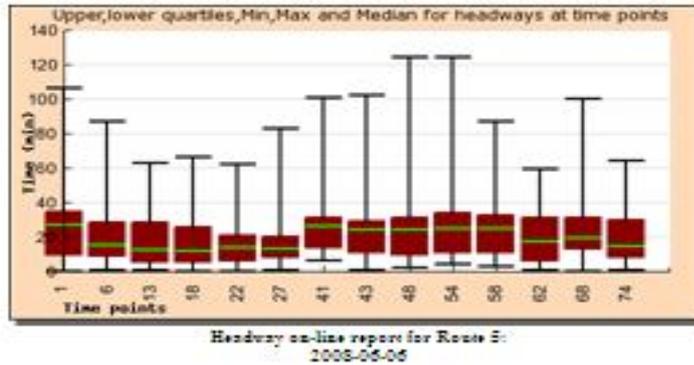
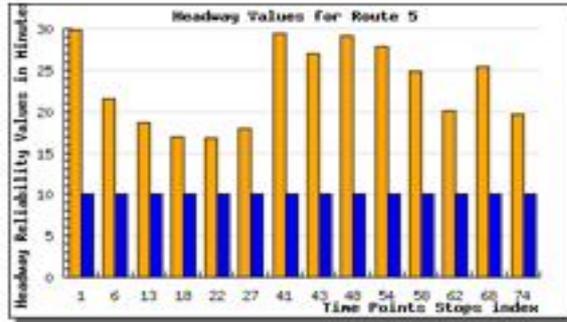
$$h_{k,i}^{(t)} = p_{k,i} - p_{k-1,i} \quad (4-4)$$

Where:

$P_{k,i}$  The departure times of vehicle  $k$  at station  $i$

$P_{k-1,i}$  The departure times of vehicle  $k-1$  at station  $i$

For high frequency routes where the scheduled headway is ten minutes or less, a headway value of over ten minutes means that the bus is behind schedule, whereas a headway value of less than ten minutes indicates that the bus might be ahead of schedule. (Nakanishi, Y.J., 1997) uses +/- 50% of the headway as a cut-off in identifying irregular service for headways of 10 minutes or less, and +/- 5 minutes for longer headways. The actual departure timestamps for the sequence of trips can be used to measure headways at the route and stop level for all time profiles. The headway deviation was also included, knowing that all services run with planned ten-minute headway. Figure (4-11) shows headway values for Blackpool bus route 5 time points including Min, Max, Median, lower quartile (Q1), and upper quartile (Q3), Headway values that are shown both graphically and in tabular format.



Headway on-line report for Route 5:  
2008-06-06

Bus/stop Index	Sched. Headway	Actual Headway	StdDev	H.R.
<a href="#">1</a>	10	29.8	28.3	0.9
<a href="#">6</a>	10	21.6	19.6	0.9
<a href="#">13</a>	10	18.6	16.5	0.9
<a href="#">18</a>	10	17	16.7	1
<a href="#">22</a>	10	16.8	15.4	0.9
<a href="#">27</a>	10	18	16.8	0.9
<a href="#">41</a>	10	29.4	24.8	0.8
<a href="#">43</a>	10	27	25.1	0.9
<a href="#">48</a>	10	29.2	29	1
<a href="#">54</a>	10	27.9	25.5	0.9
<a href="#">58</a>	10	24.9	19.6	0.8
<a href="#">62</a>	10	20.1	15.6	0.8
<a href="#">68</a>	10	25.4	20.9	0.8
<a href="#">74</a>	10	19.7	16.2	0.8

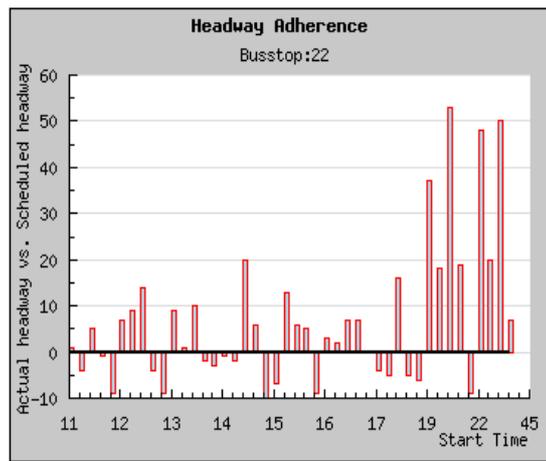
Mean Headway: 23.2  
Standard Deviation: 4.9  
Headway reliability: 0.211206896552

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Figure 4-11 Actual headway values vs. Scheduled headway in minutes

As we can see in Figure (4-11) a box plot (also known as a box-and-whisker diagram or plot) is used for graphically depicting groups of headway values: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum). A box plot may also indicate

which observations, if any, might be considered outliers. The measured headway give a clear picture of the performance. In the graphs, time points are depicted on the x-axis while the values associated with bus headways are depicted on the y-axis. It also shows the comparison between the actual headway and the scheduled headway, which makes it easier for the operator to detect and correct headway deviation. Similarly, bus stop indexes in Figure (4-12) are links to get more information, whereby clicking on one of these links we can obtain more information related to headway values for the selected stop.



Bus headway on-line report :  
2008-06-06  
Stop index :22

Bus #	Bus departure time (a)	Actual Headway in minutes(b)
252	11:30:51	
251	11:41:27	11
254	11:47:26	6
252	12:02:12	15
253	12:11:39	9
251	12:12:27	1
257	12:28:58	17
254	12:48:02	19
252	13:12:20	24
251	13:18:10	6
254	13:18:57	1
253	13:37:29	19
257	13:48:12	11
253	14:08:14	20
257	14:16:39	8

Figure 4-12 An extract of Headway adherence

Figure (4-12) shows an extract of a real-time report for headway adherence, with a bar plot of the actual minus scheduled headway for bus stop 22. The figure highlights some fundamentals of transit operations. For each arrival at a bus stop, the difference between the actual and scheduled headway oscillates between being positive and negative. Positive values show arrival behind the scheduled headway whereas negative values indicate arrival before the scheduled headway. Minimizing headway variance allows for more efficient bus operations. If a bus reaches a given stop late, there are likely to be more than the normal number of passengers waiting to board. Passengers boarding and alighting take time: as a result, a build-up of passengers at a given stop tends to result in the bus failing to adhere to the scheduled headway and falling further behind schedule. Meanwhile, the following bus, if it is on time, arrives only a few minutes after the previous bus. Because there are few (if any) passengers at each stop, the second bus steadily gains on the increasingly late bus. The result is poor service for passengers and inconsistent wait times.

Figure (4-13) summarizes the results for the headway frequency distribution measured at the route level for different day times. From Figure (4-13) we note the presence of headway irregularity as the headway distribution figures are above or below the scheduled headway which is 10 minutes. Any variation in the values of the headway above or below the scheduled headway for high frequency routes indicates the occurrence of bus bunching. This is what we observe in Figure (4-13), where the values of headway are varying. For example, there are 20 observations where the headway distribution is between 20 to 25 minutes, which is clear evidence of service irregularity.

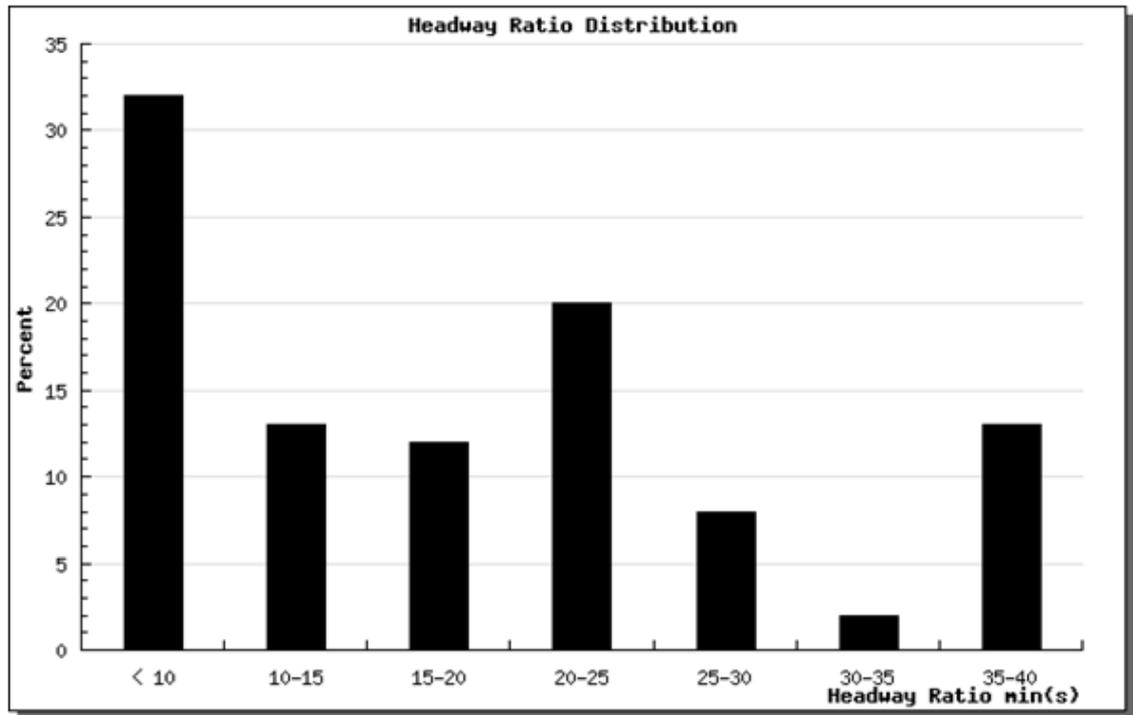


Figure 4-13 Headway distribution for a single day measured at route level

It is important to devise a useful measure to assess the quality of service in aspects of reliability. A number of different reliability measures have been proposed in the literature (Oort, N and Nes, R. 2003; Yin, Y et al., 2004). In this research, we adopt the definition of (Bowman, L.A. and Turnquist M.A., 1981) and define headway reliability as the standard deviation over mean headway. This is a further measure derived from the computation of the headway.

$$RH_i = \frac{\sigma_{hi}}{\mu_{hi}} \text{ for } h \in \{h_{inms}\} \quad (4-5)$$

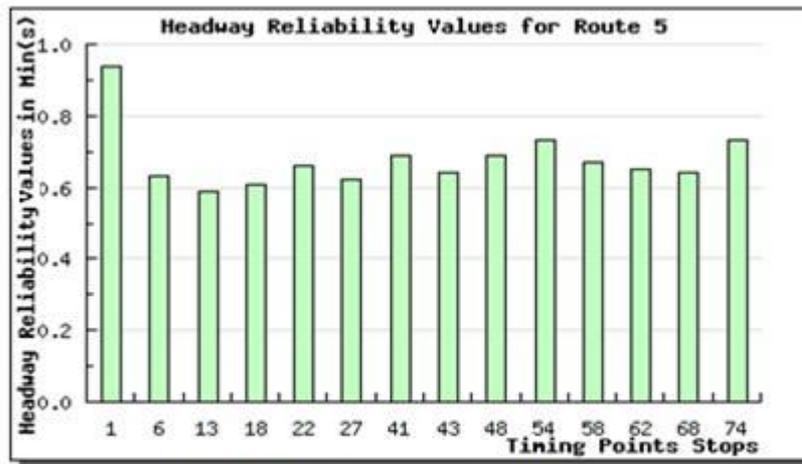
Where

$\sigma_h$  Standard deviation of sample  $\{h\}$

$\mu_h$  Mean of the sample  $\{h\}$

$h_{inms}$  Headway between bus trip  $n$  and  $n+1$  on day  $m$  at bus stop  $s$  along route  $i$

Smaller values of *RH* indicate better headway reliability. This measure represents the coefficient of variation of the headway. Headway reliability can be measured on any given bus stop for any time period. Headway reliability values for fourteen time points of Blackpool city route 5 are measured and visualised as a bar graph as shown in Figure (4-14).



Headway Reliability on-line report for Route 5:  
2008-06-27

Mean Headway: 18.4  
STD:6.6  
Overall Headway reliability:0.36

Busstop no	Mean Headway	STD.	Headway Reliability
1	41.4	39	0.94
6	16.9	10.7	0.63
13	17.4	10.3	0.59
18	17.4	10.6	0.61
22	16.5	10.9	0.66
27	17.3	10.8	0.62
41	16.7	11.6	0.69
43	17.3	11.1	0.64
48	16.4	11.3	0.69
54	15.6	11.4	0.73
58	16.4	11	0.67
62	16.5	10.7	0.65
68	17.5	11.2	0.64
74	14.9	10.9	0.73

Figure 4-14 Headway reliability for fourteen timing point stops of Route 5

The headway reliability values fall between zero and one and smaller values of  $RH$  indicate better headway reliability. Headway reliability values are measured at each timepoint and range from 0 to 1 with a higher value indicating a more dispersed distribution. Ideally, the coefficient of variation for each timepoint would be 0, indicating deterministic headways. (TCRP, Report 100) states that as the coefficient of variation increases, the probability of bunched buses goes up, and level of service goes down.

The system also calculates the headway regularity index, which is another indicator to measure headway regularity that performs well to identify bus bunching (Shalaik, B. and Winstanley, A.C, 2009). A high headway regularity index value indicates a regular headway, whereas low numbers indicate headway irregularities. The formula of the headway regularity index is as follows:

$$R = 1 - 2 \sum_{r=1}^n \frac{r(h_r - H)}{n^2 * H} \quad (4-6)$$

Where:

$R$  Headway regularity index

$r$  Rank of headways 1..  $n$

$n$  Total number of headway measures

$h_r$  Series of headways

$H$  Mean headway

When the headway measures are equal for  $n$  observations, then the headway regularity will be 1. The larger the difference between the headway observations, the smaller the headway index ( $R$ ) will be. Figure (4-15) illustrates headway index value for the stop “Corporation Street C3” calculated and depicted on the transit map.

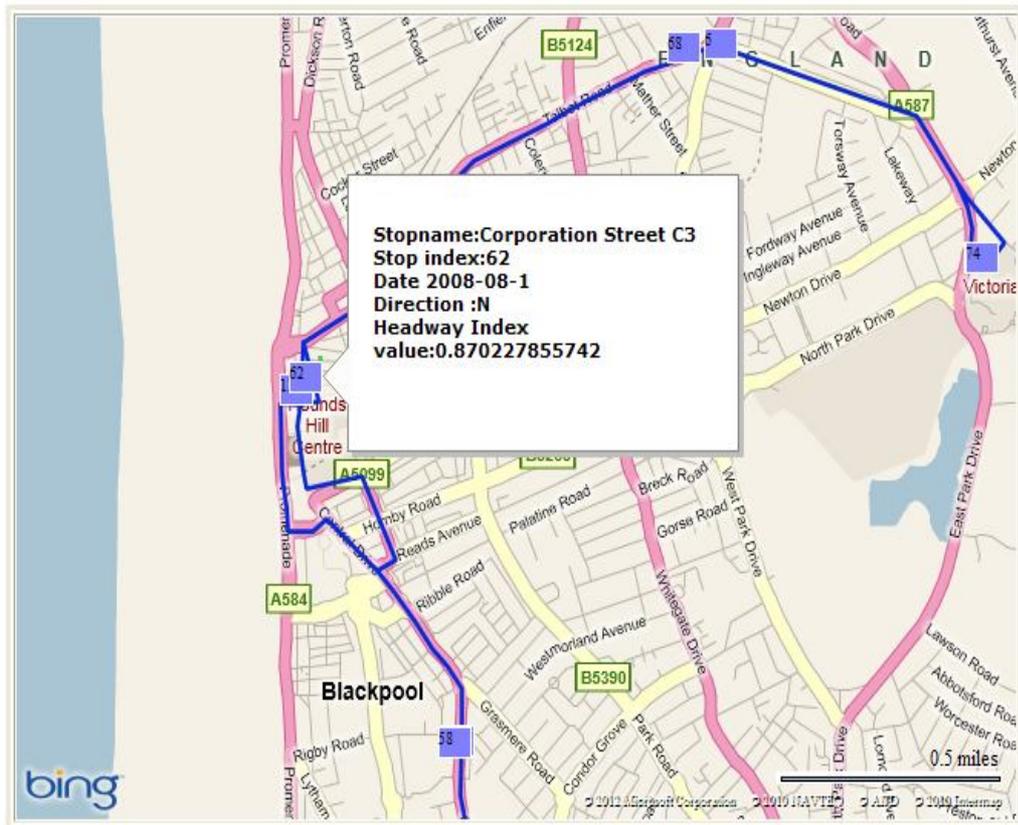


Figure 4-15 Headway index value for stop number 62

The value of 0.87 indicates that headway index for the measured bus stop is high indicating a more regular headway.

#### 4.5.4 Measuring Travel Time Reliability

Travel time reliability focuses on the variability in bus journey times for a specific bus route, or with a specific time interval and at a specific level of service, or the probability that a trip can be completed within a given time. Travel time reliability is defined as the inverse of the standard deviation of bus travel times. A high reliability is indicated when the variability is small (Polus A.1978; Steman and Schofer 1976). Another definition of travel time reliability is “the consistency or dependability in travel times, measured from day to day for the same trip” (Kate, L. et al., 2008). Passengers on well-known routes learn to adapt to possible unexpected events and adjust their travel time budget accordingly. Their experience will vary day-to-day for the same trip in services with unreliable travel times. In this research, we measure travel time reliability as the mean over the standard deviation of the travel time. The inclusion of the mean in addition to the standard deviation is to allow for comparison

of the variations in bus routes or sections of a route that have significantly different mean values. This definition can be written as:

$$RT_i = \frac{\mu_{ti}}{\sigma_{ti}} \quad \text{for } t \in \{t_{inm}\} \quad (4-7)$$

Where

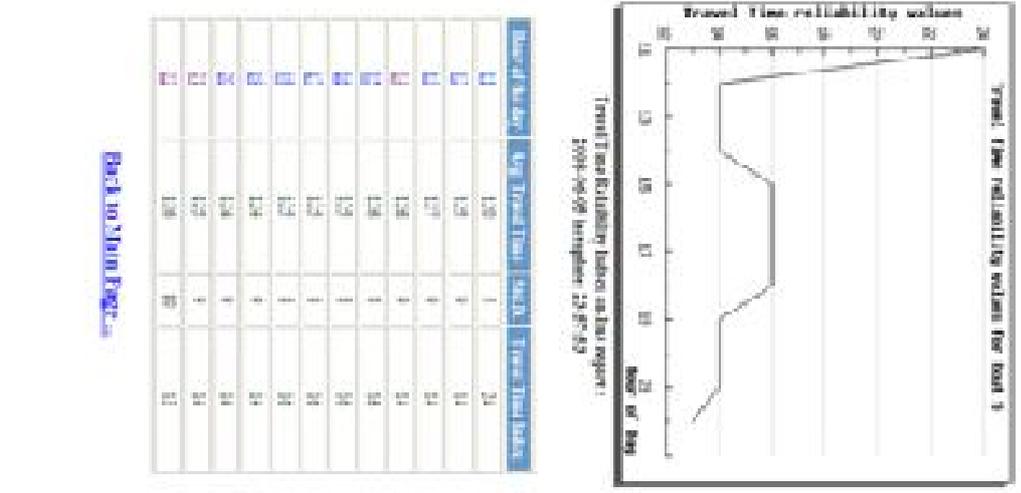
*RT* Travel time reliability

$\mu_{ti}$  Mean of travel time of route *i*

$\sigma_{ti}$  Standard deviation of travel time

$t_{inm}$  Travel time between bus stop *n* and *n+1* on day *m* along route *i*

Travel time variability can be measured for a whole route or sections of route. A higher value of *RT* indicates better reliability. Travel time reliability for route 5 in Blackpool city was studied and measured for the whole route and sections of the route. Whole route reliability was measured for working hours while buses were in service, while another measurement was conducted for route segments that included timing points. In Figure (4-16) travel time reliability values at different times of the day have been calculated and are shown in graphical and tabular format. A line plot represents the variation at travel time reliability. Times of the day are depicted on the x-axis while the value *RT* is depicted on the y-axis.



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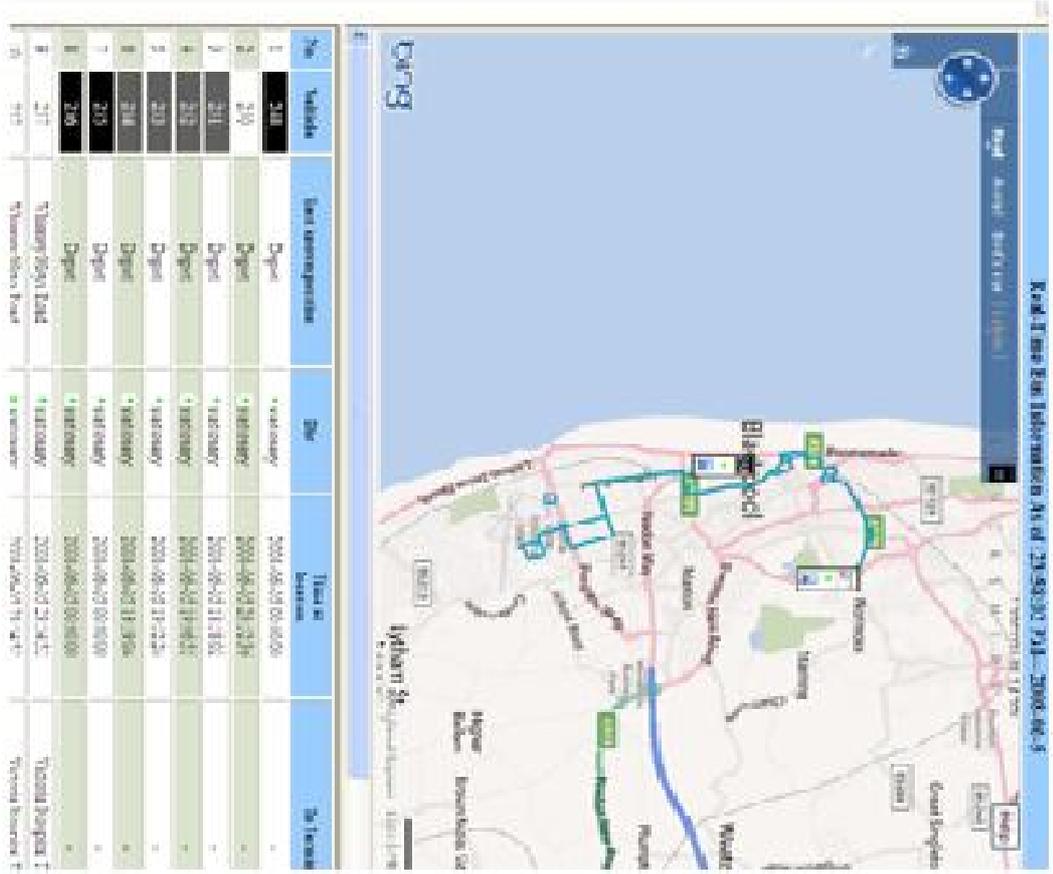


Figure 4-16 Travel time reliability values for transit route 5

Blackpool city transit route 5 contains fourteen time point bus stops, each of which has a timetable, used to check and maintain the adherence to the timetable. We measured travel time reliability for bus route segments in seconds and values are shown in Figure (4-17).

As we can see in Figure (4-17) travel time reliability values for route 5 between different route segments are measured and shown. For example, 166 seconds is the average travel time between time points 1 and 6 on the first route segment, 60.3 is standard deviation of these travel time values and 2.8 is travel time reliability value, which indicates a low reliability. Travel time reliability values are depicted graphically in Figure (4-17), Y-axis to represent the values of travel time reliability, while the x-axis to shows route segments.

**Travel Time Reliability on-line report for Route 5:  
2008-06-29**

From_To	Avg.T.T	STD.	Travel Time Reliability
1-6	166.7	60.3	2.8
6-13	580.8	96.4	6
13-18	449.1	105.4	4.3
18-22	324.1	95.6	3.4
22-27	229.7	49.5	4.6
27-41	652.9	105.4	6.2
41-43	123.1	49.9	2.5
43-48	243.7	82.1	3
48-54	300.6	69.5	4.3
54-58	252.8	130.4	1.9
58-62	379.3	201.6	1.9
62-68	379.6	108.6	3.5
68-74	297.6	133.1	2.2

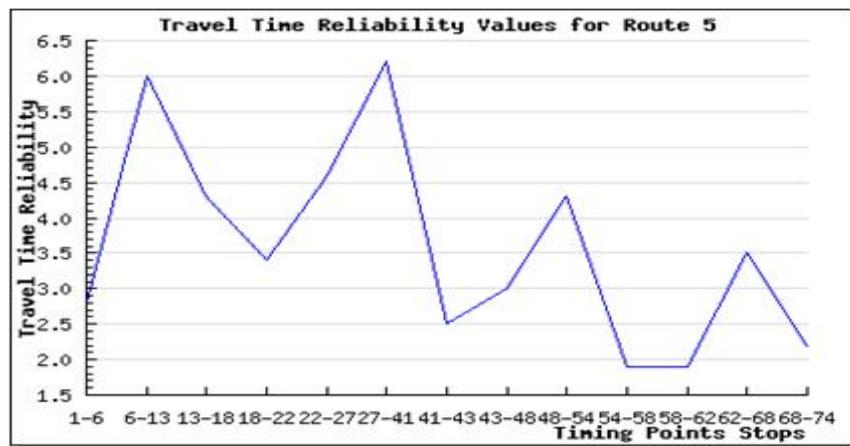


Figure 4-17 Travel time reliability values of route 5 sections

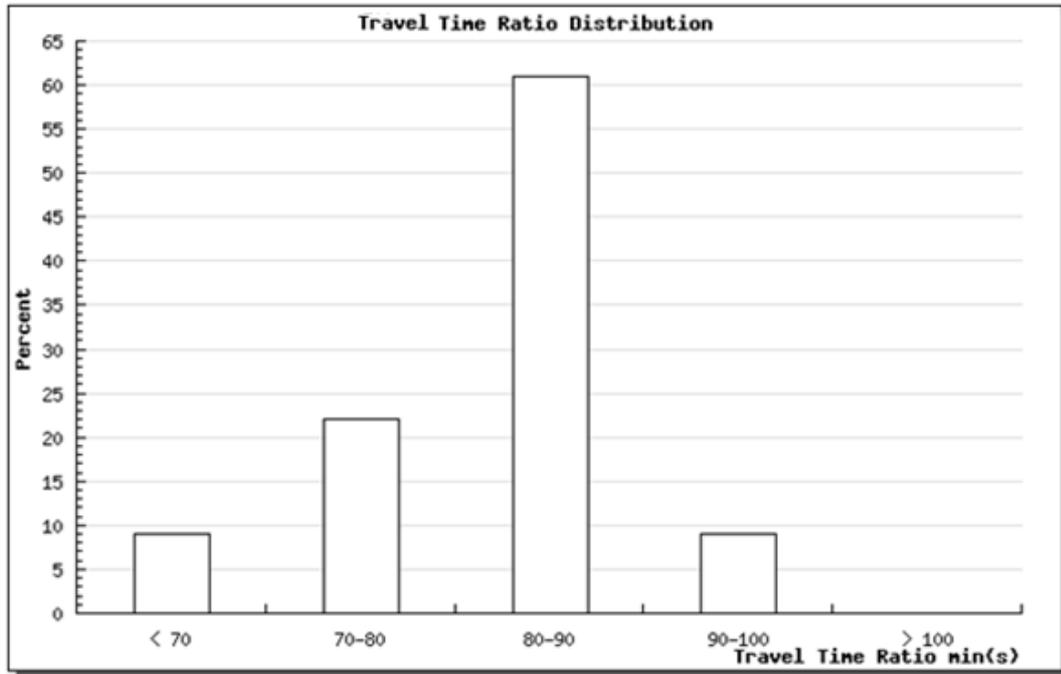


Figure 4-18 Frequency distribution for the Travel Time Ratio

Figure (4-18) presents the frequency distribution for the travel time ratio. If we knew that the scheduled travel time is 84 minutes then nearly 60 % of trips surveyed had travel times that were within +/- five minutes of schedule. Travel time variability can be calculated for any given time, and is defined as the difference between the actual travel time and scheduled travel time.

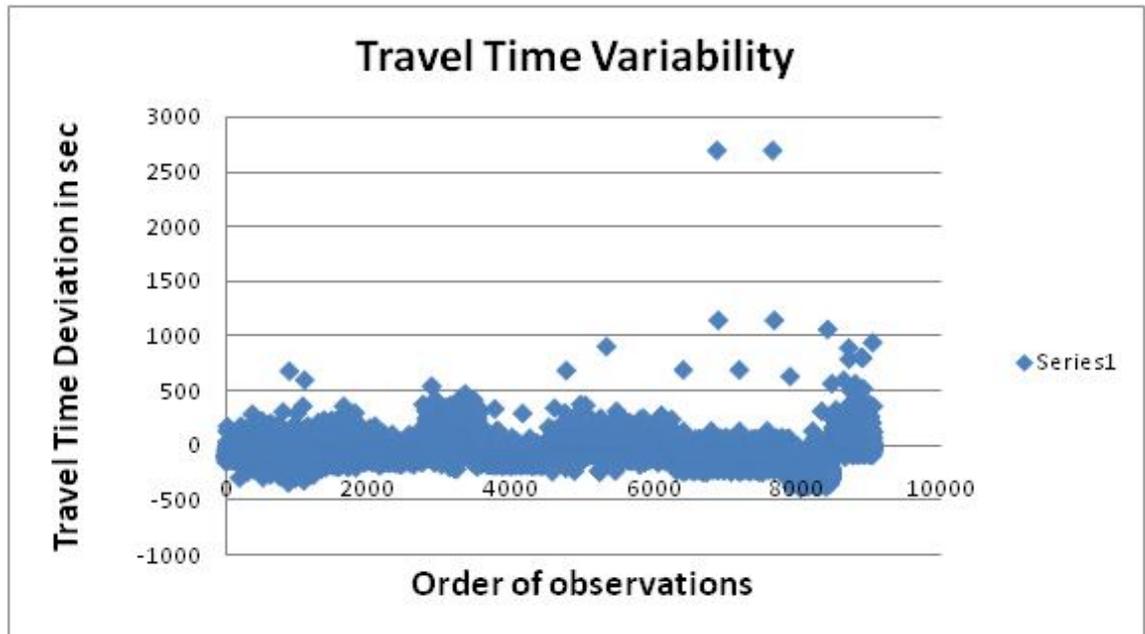


Figure 4-19 Travel time variability for all working days of June 2008

Figure, (4-19) depicts travel time variability for a bus route on a working day of June 2008. We used the residual to represent the difference between the observed travel time and the value of scheduled travel time. Travel times values are equally represented about the x-axis, while travel time deviation in seconds is depicted on the y-axis. As we can see, the travel time values points in a residual plot are randomly dispersed around the horizontal axis and most of the differences between actual travel time and the scheduled travel time is limited between +/- 500 seconds, however, some observations of travel time variability reaching 2700 seconds indicating a notable deviation in bus travel time.

#### ***4.6 Tools for Transit Data Visualisation***

Visualisation is a process of transforming data into a visual form, enabling the user to better understand and extract the information contained (Winstanley A.C. et al., 2009). Over the last ten years, computer-based visualisation technologies have become a powerful tool for studying a variety of natural phenomena. These visualisation technologies are used in areas such as medicine, architecture and engineering. Continuous advances in computer technology have made visualisation techniques available and affordable to the transportation industry. In the

transportation industry, visualisation is a science that combines a variety of different applications and technologies such as graph, image, video overlay to generate and portray existing and proposed transit data.

Transit data can be visualised dynamically or statically through tables, maps, data plots and other graphical outputs for transit information dissemination and within the context of performance monitoring (Thomas, J., 2007). For real-time visualisation of transit data, such as the current/last vehicle location or time at location, real-time data sources from the vehicles are required. Effective visualisation significantly improves the analysis of transit data. It also helps transit users to extract information in an easy-to-understand way. Colour-coded and time-space diagrams are among the visualisation techniques that are used in transit data visualisation (Thomas J. K., (2007).

#### *4.6.1 Visualising Service Gap and Breakdown*

In transit services, a large gap between buses often leads to several buses behind bunching together. Transit users complain of large gaps in service followed by several buses coming at the same time. Service gaps are associated with long wait times and could be a sign of unreliable transit service. A big gap in service is defined as “an interval between buses that is greater than either double the scheduled headway or fifteen minutes, whichever is greater” (Milkovts, M., 2008). This interval is unacceptable and should be reduced. Large gaps and wait time are highly correlated and transit users are directly affected by the number of gaps in the service. Large gaps in the bus route reveal how service could be improved where gaps should decrease. Time-space visualisation graphs are used to show the service gap of bus routes. Figure (4-20) provides an example illustrates gaps between bus services.

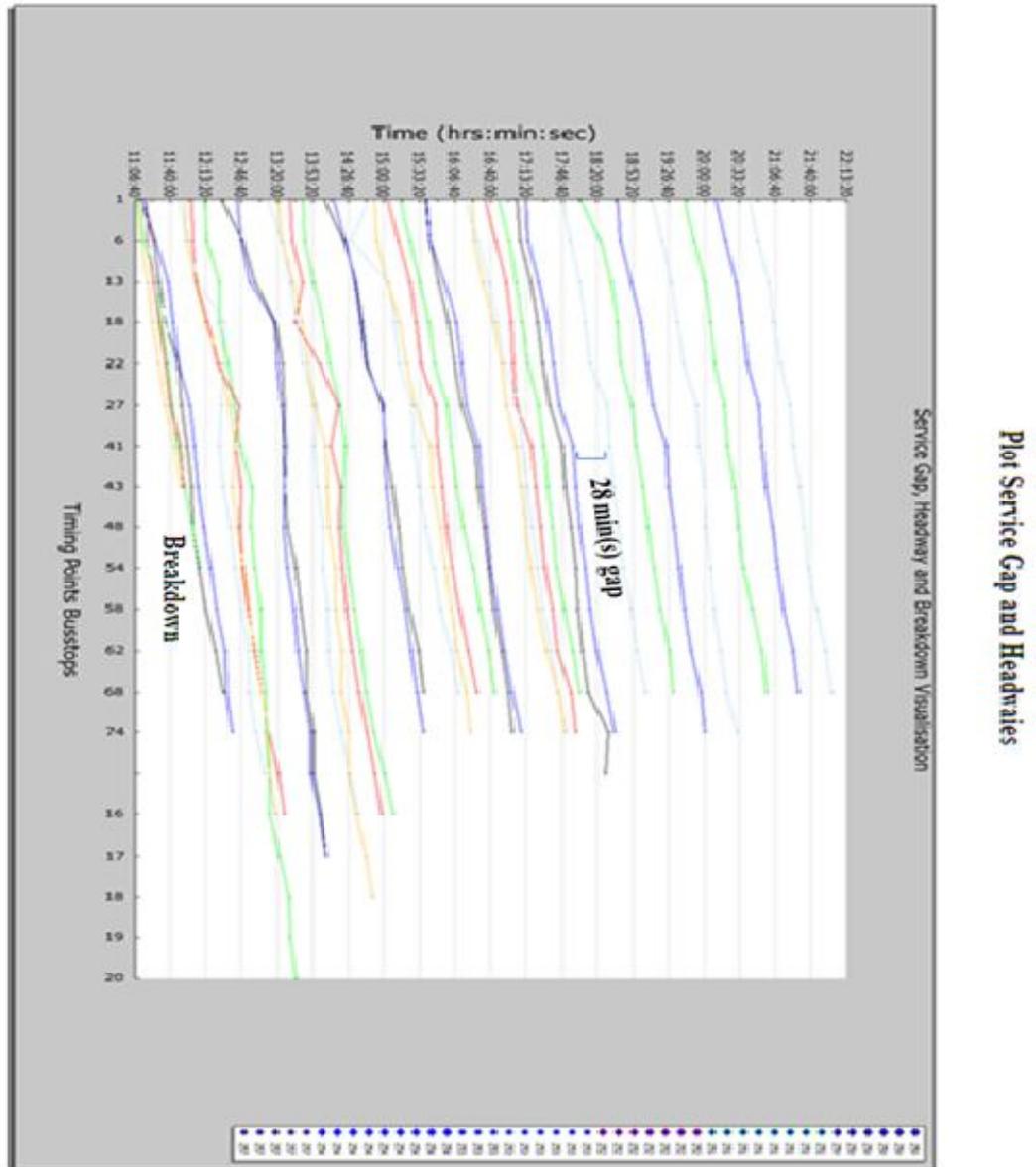


Figure 4-20 service-gap visualisation

From Figure (4-20), the time difference between two services can be seen as a gap on the graph between two lines. For example, a time gap of 28 minutes is illustrated between two buses services.

#### 4.6.2 Measuring and Visualising Schedule Adherence

Schedule or timetable adherence is one of the indicators to measure transit service reliability. Measuring schedule adherence is a valuable management tool, because good schedule adherence demands both realistic schedules and good operational

control. The schedule adherence indicator measures the schedule adherence for transit vehicles at bus stops (Strathman, J., et al., 1998). Adherence to the published schedule is calculated by subtracting the scheduled arrival time from the actual arrival time. A negative value for the arrival time indicates that a vehicle has arrived early. Likewise, a positive value for the arrival time means that a vehicle is late.

To indicate transit vehicle schedule adherence, it is better to visualise their adherence status. (e.g. on-time, ahead, or delayed). A colour-coding-based visualisation technique is used to display vehicle adherence. Measuring and visualising the timetable adherence of transit vehicles helps transit operators in managing transit services. The red colour is used when buses arrive late to a bus stop, while the green colour indicates on-time arrival and the orange colour is used when buses are ahead of their timetable. Figure (4-21) illustrates the use of coloring to indicate buses adherence status to published timetables.

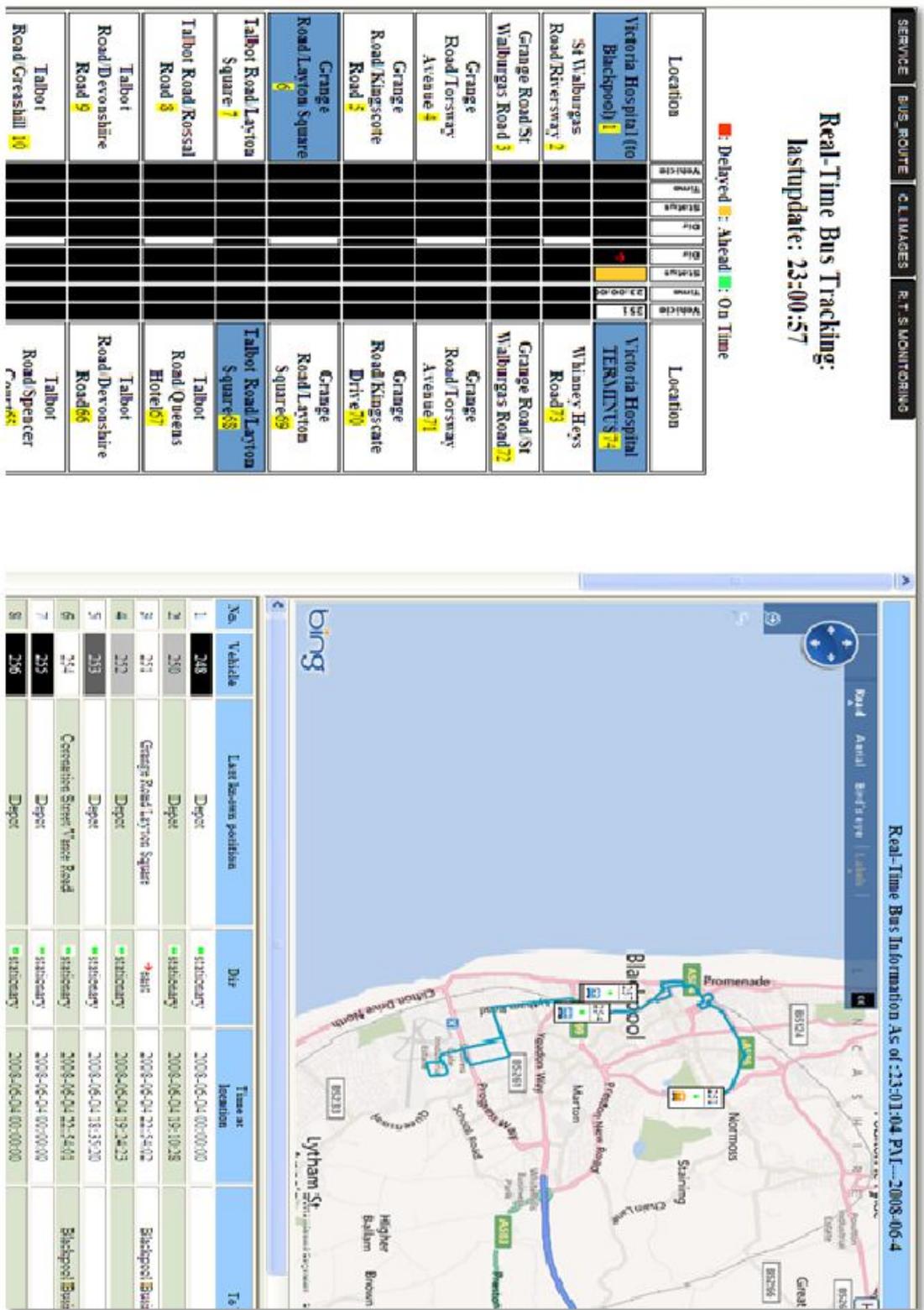


Figure 4-21 The use of colour coding to indicate the adherence of buses on map-based and tabular-based views.

The adherence to the published schedule can also be visualised on other various diagrams. A bus route progress diagram, as we can see in Figure (4-22), shows the current location of a transit vehicle, with a colour-code indicating its adherence to the timetable. The Figure also shows the transit vehicles that are out of service by the black colour.



Figure 4-22 The current location of a transit vehicle, with the green coloured boxes indicating on time arrival

Figure (4-22) is useful for passengers who are not familiar with maps as they can easily locate where transit vehicles are at any given time. For example, the bus number 254 is at the station (Grange Road/Kingscate Drive) is colored in green to indicate on-time arrival. The rest of the buses at the bottom of Figure colored black to signify they are out of service at that time.

A real-time report for transit vehicle adherence can be generated for monitoring the adherence to the time table and detecting any deviation from the planned schedule. As we can see in Figure (4-23), the schedule adherence monitoring reports are generated in real-time. In these reports the system measures the adherence to timetables and assigns a specific colour based on the adherence status (on-time, ahead or late). For example, the bus-adherence reports indicate vehicle number, the actual arrival times, scheduled arrival time, time difference in minutes and schedule adherence status.

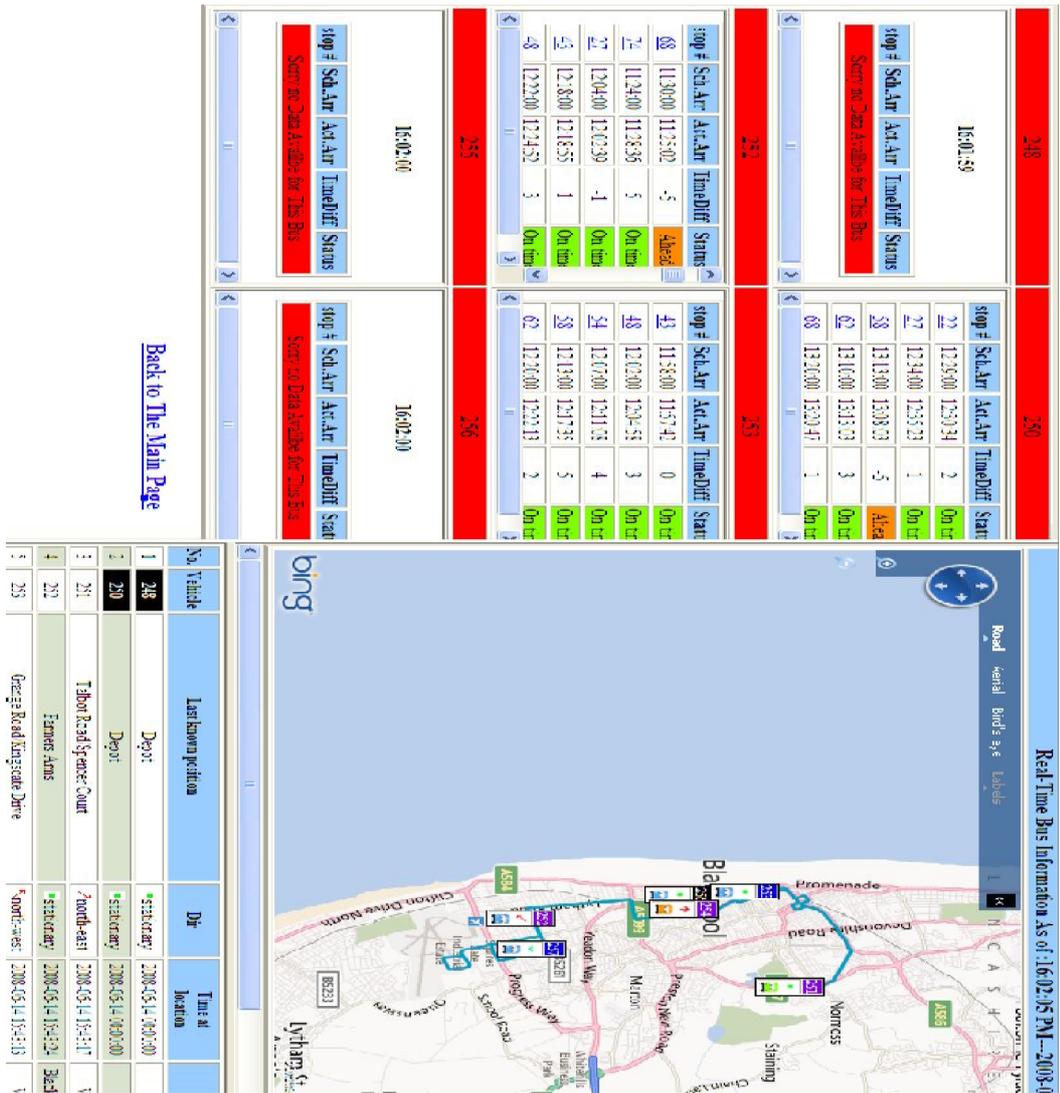


Figure 4-23 Real-time schedule adherence monitoring

Instead of using a tabular format to compare transit vehicles' actual performance against the timetable, visualising this comparison may be of more use in this context. Figure (4-24) shows the visualisation of vehicle behaviour and a comparison with the timetable, showing adherence and deviation.

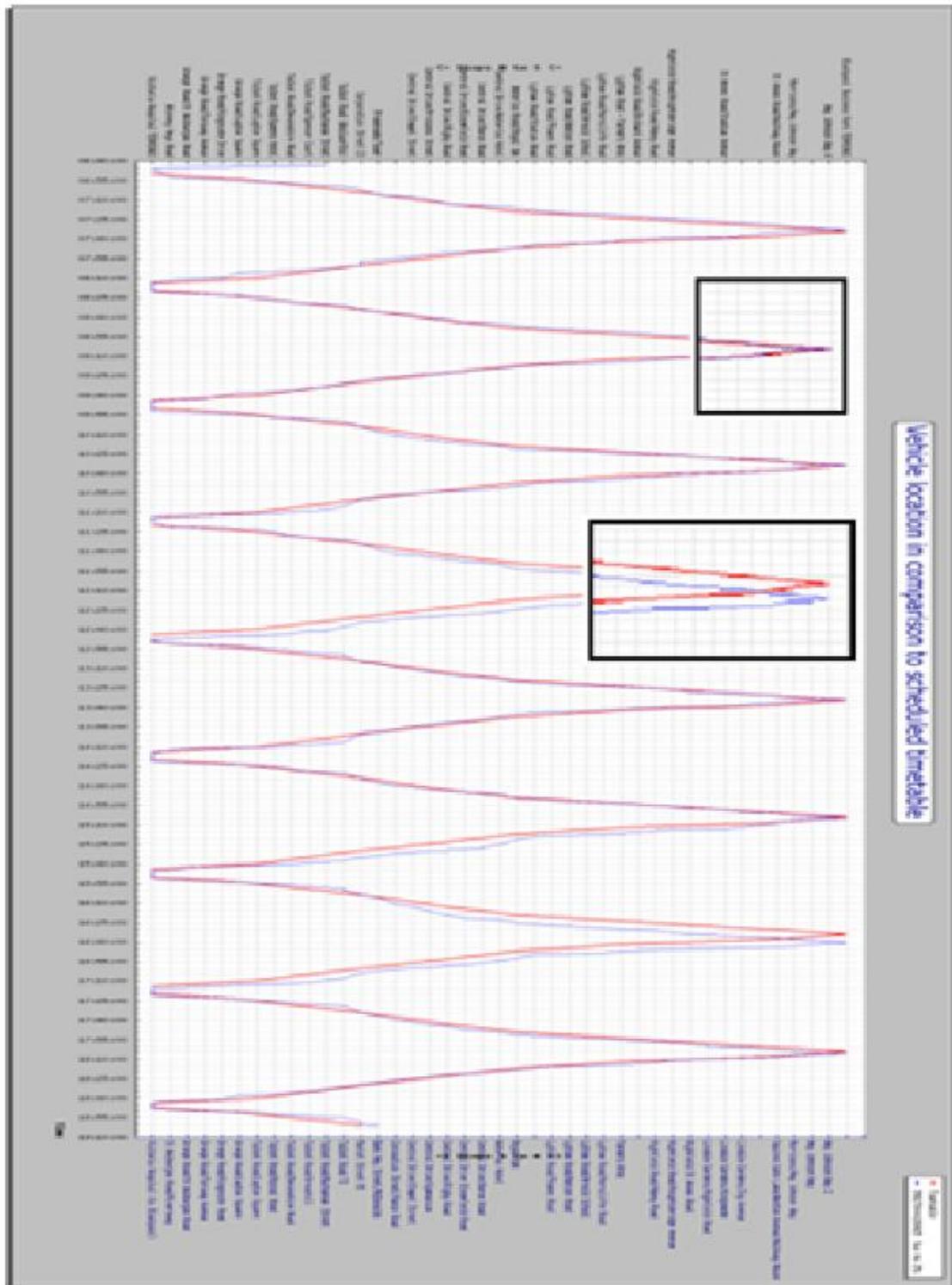
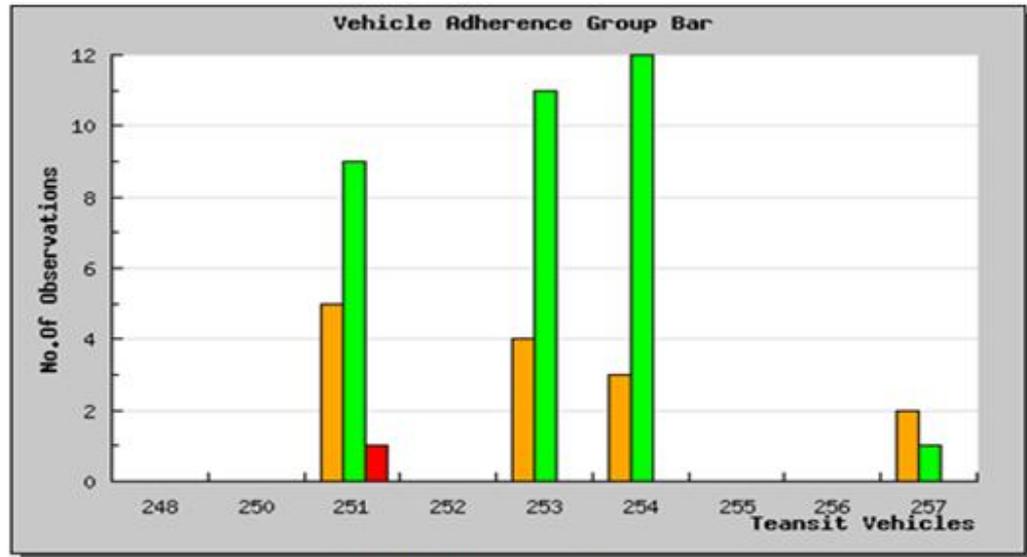


Figure 4-24 Visualisation of vehicle behaviour and a comparison with the timetable, showing the adherence and the deviation

Figure 4-24 illustrates the daily spatial-temporal “behaviour” of transit vehicles (vehicle locations in term of bus stops passed against time) as a series of line-graphs.

Buses move along the route to complete their journeys, this has been represented by a blue line which shows bus location and time to be compared to the timetable (in red) showing the adherence deviation. Figure 4-24 provides insight into the relationship between actual and scheduled service on a per trip basis. This method of data visualisation can help to show the regularity of the service and indicate irregularity. For example, in this figure the line graph in red represents the timetable while the line graph in blue represents the actual running of a transit vehicle. The figure shows two cases where in the first one the transit vehicle follows the timetable, while in the second case a deviation from the timetable can be detected easily where the difference between the timetable and the actual performance of the bus has been represented using a line plot. This way of visualisation shows the difference between the space and time data for both the transit vehicle and timetable.

Factors that influence adherence to the timetable can be classified into two categories: internal and external factors. Internal factors such as variations in passenger demands, route configuration and driver behaviour, and external factors such as traffic congestion, weather conditions, bus bunching and others can effect transit vehicle operations and make it difficult for them to adhere to the published timetable (Zolfaghari, S. et al., 2002). Our system provides pictorial and tabular views that depict adherence to the timetable. Figure (4-25) shows use of color-codes in a real-time updated report for the number of times transit vehicles were on time, early, or delayed at timing points. In this figure, we used a bar graph to represent transit vehicle adherence. As we can see in the bar-graph transit vehicle numbers are depicted on the x-axis, while the number of times the vehicle was on time, delayed or ahead are depicted on the y-axis. We used colour-coding for transit vehicle adherence as we discussed in Section (4.6.2). The table in the figure shows time points and vehicle number as well as number of times these vehicles adhered to the timetable. For example, vehicle number 254 was 12 times on time and 3 times early and zero times in its arrival at bus stops.



Vehicle Adherence on-line report :  
lastupdate: 01:45:26

Stopindex	248	250	251	252	253	254	255	256	257																		
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0					
6	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0		
13	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	
18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	
27	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	
41	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	
43	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	
48	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	
54	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	
58	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	
62	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	
68	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	
74	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	
Total:	0	0	0	0	0	0	5	9	1	0	0	0	4	11	0	3	12	0	0	0	0	0	0	0	2	1	0

Figure 4-25 Adherence table shows time points and number of time transit vehicles were on time, early or delayed

Schedule adherence can be described as the percentage of departures that were in a defined on-time window, or perhaps as the percentage that were ahead, on time, and delayed. Figure (4-26) shows a distribution of schedule deviations in full detail. Such a distribution allows operators to vary the “ahead” and “delayed” threshold depending on the timetable difference.

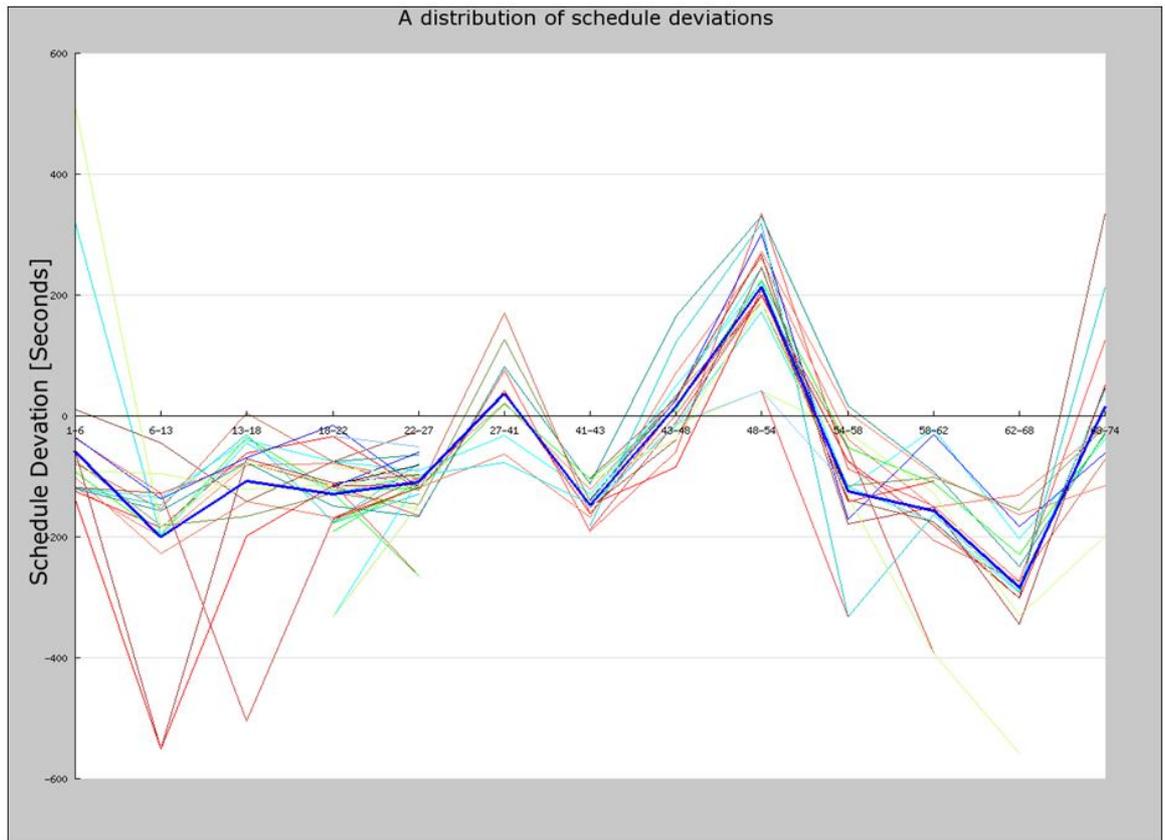


Figure 4-26 A distribution of schedule deviation

A profile of schedule deviations along the line is a valuable tool, showing how both the mean and spread of schedule deviation changes from stop to stop. The heavy blue line indicates mean schedule deviation. Thin lines represent individual observed trips. How close the mean deviation is to zero indicates whether the scheduled running time is realistic. If the mean deviation suddenly jumps, it suggests that the allowed segment time is unrealistic. Our system can help in measuring the vehicle's timetable adherence in detail and provide the distribution of the time difference between the actual performances and the timetable. As we can see in Figure (4-27) the time distribution shows how transit vehicles act against the timetable. Most of the transit vehicles appear to adhere to the timetable, where the distribution is concentrated around zero. We also note cases where the deviation from the timetable is high such as 10 to 12 minutes. This evaluation of the transit vehicles' performance can be measured for any given vehicle at any given time along the route and helps to maintain and control the schedule and enhance the accuracy and reliability of transit services.

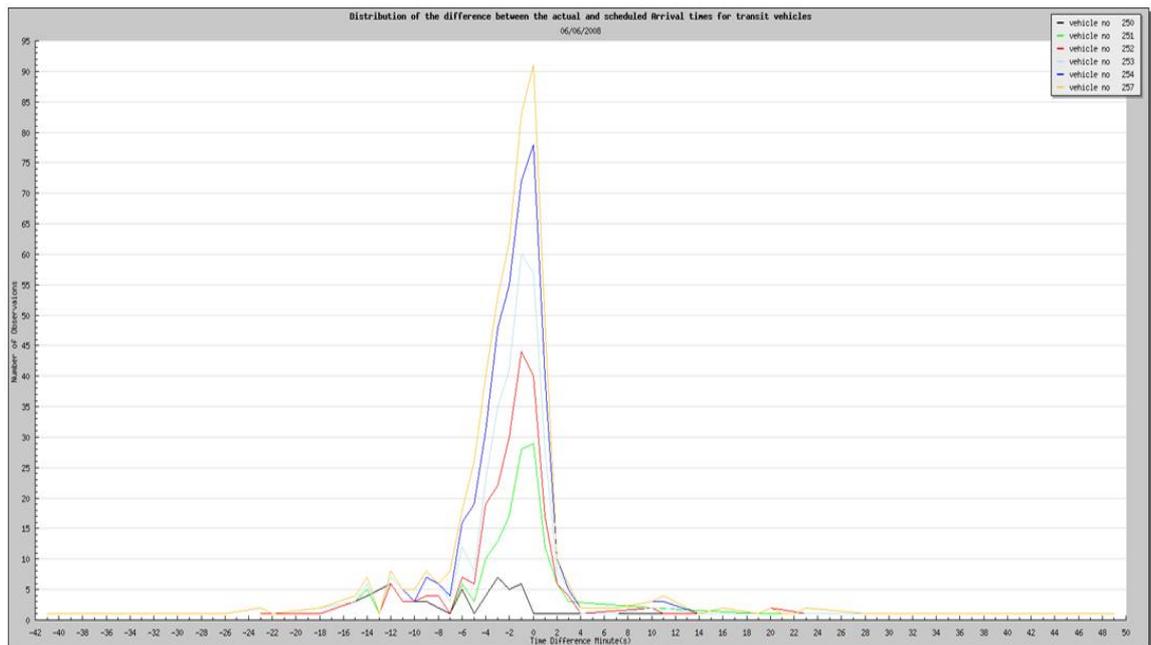


Figure 4-27 Transit vehicle adherence and time distribution

By examining the shape of the distribution, it is possible to compare proportions of on-time, early and late services and obtain a general idea of the transit services. This can be useful to compare transit vehicle adherence over different time intervals (hours, days, months).

#### 4.6.3 Transit Vehicle Trajectory Visualisation

Transit operating speed and travel time affect service attractiveness and efficiency. They provide an overview about how the transport system performs, which can be used for the service planning and management process. Average speed and travel time are critical measures for both the transit users and transit providers (Bertini, R. L., and A. El-Geneidy. 2003). To make it possible and easy to examine and extract average speed, our real-time bus tracking system can visualise the trajectory of a vehicle's trip for any given time to extract the required transit information. Transit vehicle trajectory can help the operators to examine the average speed of transit vehicles as well as comparing the average speed throughout the entire day or different times of day. The trajectory is plotted in a time-space plane where the x-axis is time and the y-axis is travelling distance. As we can see from Figure (4-28), the slope of the trajectory at any given point is the speed. With a trajectory

visualisation view, it is possible for transit operators to see how the speed of each vehicle changes with the time and distance.

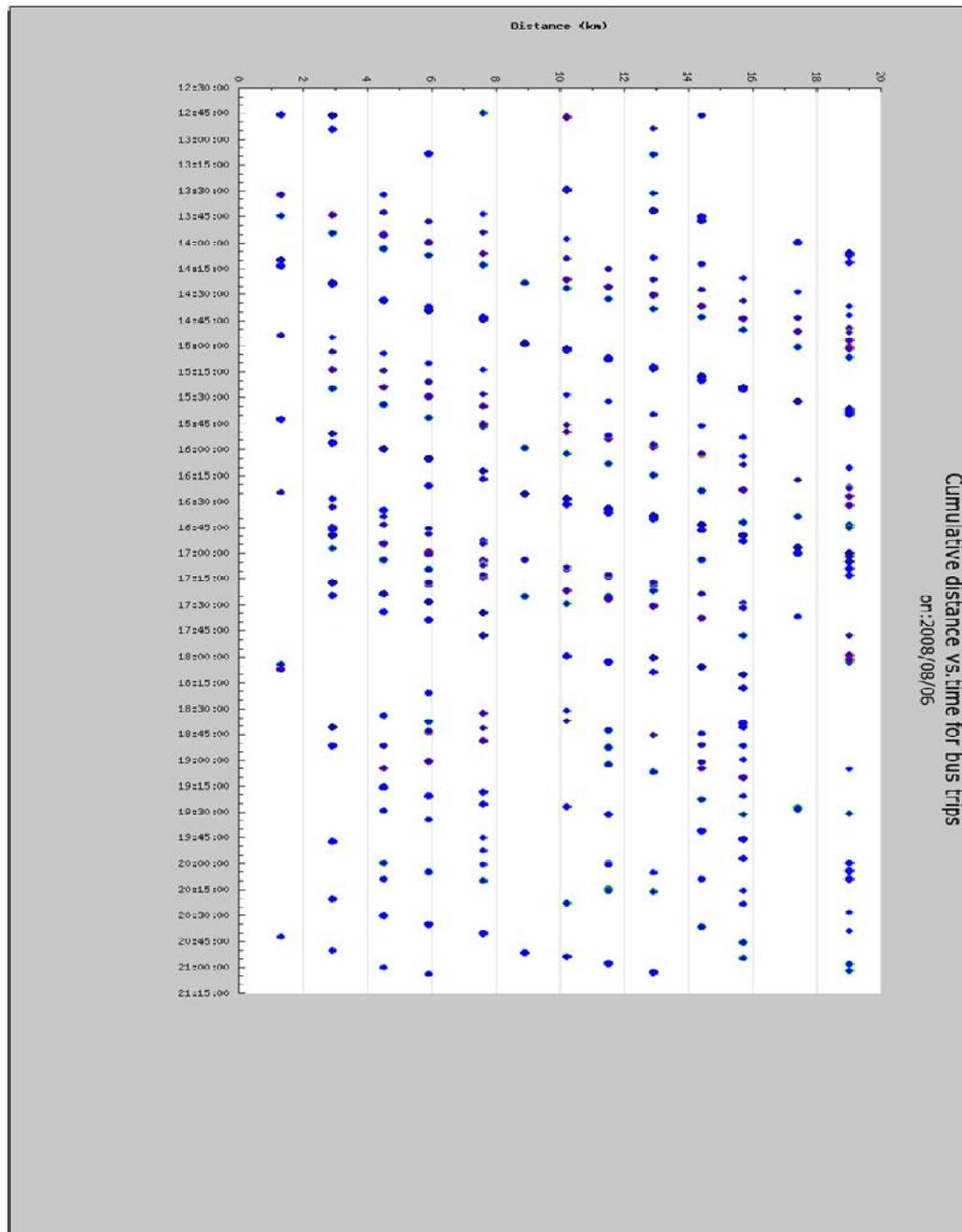


Figure 4-28 Cumulative distance vs. time for bus trips on a particular day

The time-distance diagrams are well known in transportation engineering (Mathew, B, et al, 2007). They can show buses appearing and disappearing in the middle of their route. This may reflect errors in the association of buses to routes, or prolonged periods of time when buses were either not reporting location data or reporting data at significant distances away from their route. However, it is possible for someone with proper training to scan time-distance graphs like those provided and immediately recognize when and where there are problems associated with the actual provided bus service.

#### ***4.7 The Mean Absolute Error for Timetable Matching***

Due to some transit operational conditions, transit providers may change an individual vehicles route allocation drivers timetable on a daily basis to maximise transit fleet utilisation. This may make it difficult to know which vehicle is working for a given timetable and calculate the timetable adherence. We adopted techniques such as the Mean Absolute Error (*MAE*) (Naveen K., et al 2011) to calculate the difference between the actual execution of transit vehicles and the timetable time series values, to see how close the nominated vehicle's graph is to the published timetable. The formula for *MAE* is:

$$MAE = \frac{1}{n} = \sum_{t=1}^n |V_t - T_t| \quad (4-8)$$

Where

*MAE* Mean Absolute Error

$V_t$  Transit vehicle time point

$T_t$  Timetable time point

$n$  Number of Observations

*MAE* measures how well graphs fit the timetable and can calculate the difference between time series points. If these points are identical, the *MAE* value is equal to

zero. In our implementation of *MAE*, a smaller value indicates greater closeness between the vehicle graph and the timetable. Figure (4-29) shows the implementation of *MAE* to find the best match for the published timetable. In this figure, vehicle number 254 is found to be the vehicle with minimum *MAE* values.

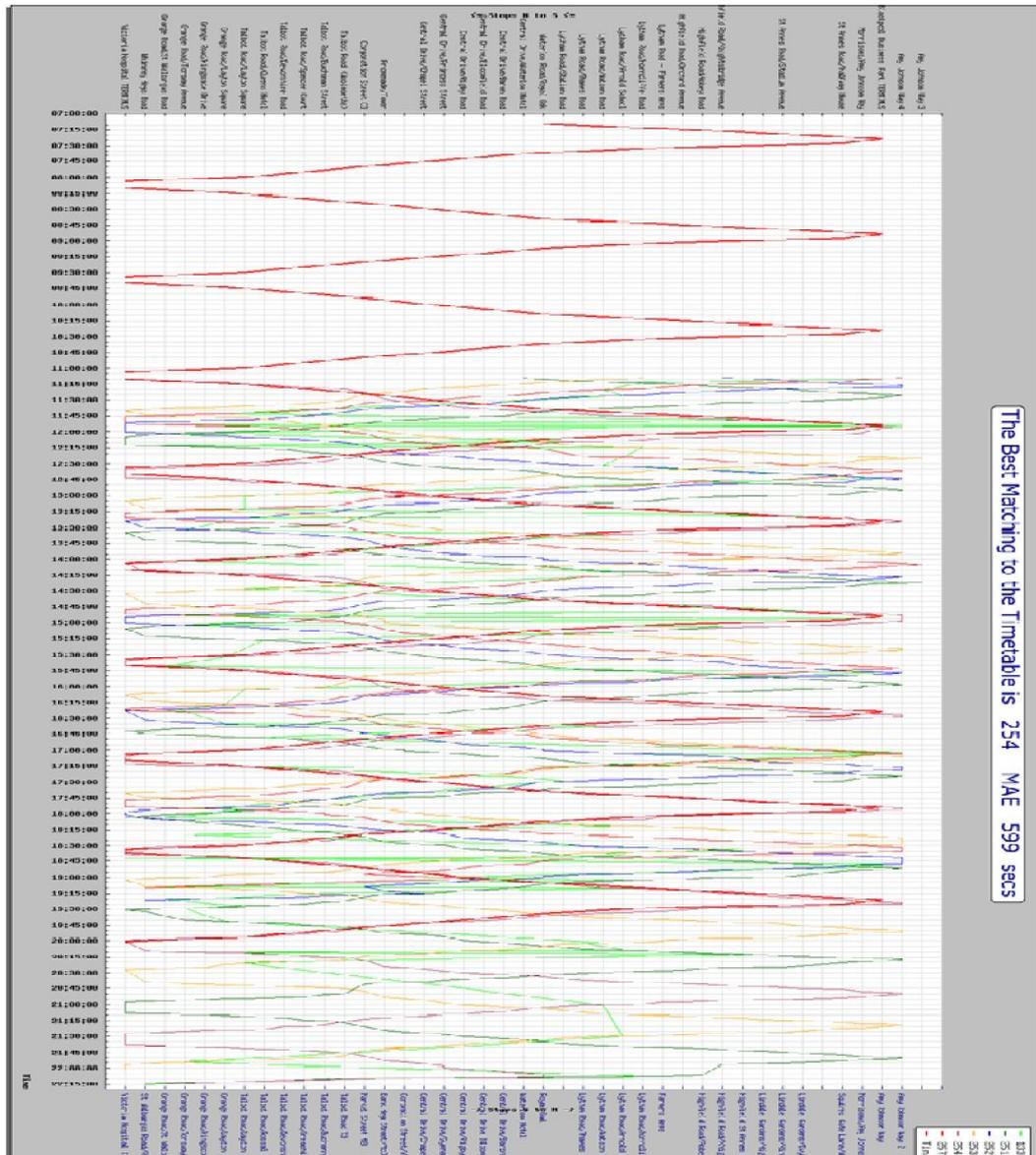


Figure 4-29 Implementation of MAE to find the best match of the published timetable

## ***4.8 Bus Bunching Detection***

Bus bunching is the phenomenon whereby a bus that is late tends to get later and later as it completes its run, while the bus following it tends to get earlier and earlier. The result is that two buses eventually form a pair, one right after another, and the service breaks down as the headway degrades from its normal values. Bus Bunching is defined as the case when two or more buses serve a route in close proximity, usually within a minute of each other (Zolfaghari, S. et al., 2002). More quantitatively, bus bunching and gaps in services are the natural state of an unreliable transit system. Many factors can cause buses to be bunched, this may include; uneven passenger loading patterns, traffic congestion, unexpected events on the street, weather conditions, and others. For example, when there is uneven passenger loading, a bus further behind the one in front (leader) must pick up more and more passengers, extending the problem. The bus then gets closer to the bus behind (the follower), while the follower picks up and drops off fewer passengers, allowing it to close the gap with the bus in front. Now two buses are travelling together, serving the same bus route. (Daganzo, F., 2009) stated that it is well known from experience that the collective buses' motion for high frequency routes is unstable: i.e. that even if one starts with perfectly even headways, they invariably become irregular. Bus bunching affects both transit users and operators. For transit users, bunched buses will create longer passenger wait times by creating longer service gaps and uneven distribution of passengers across buses. It could also increase in-vehicle time and travel time. For transit operators, bus bunching can increase the operations cost through the inefficient use of transit vehicle capacity, and also increase headway irregularity and poor on-time performance.

In this research, we propose visualisation techniques to facilitate the detection of bad service symptoms such as bus bunching. Graphical-based views were designed to visualise transit data. Different colours are used to represent different transit vehicles. In addition to showing the regularity of the service, the graphical views show poor service phenomena such as vehicle bunching and erratic service intervals. Figure (4-30) and (4-31) show the spatial-temporal behaviour of vehicles indicating a case of bus bunching.

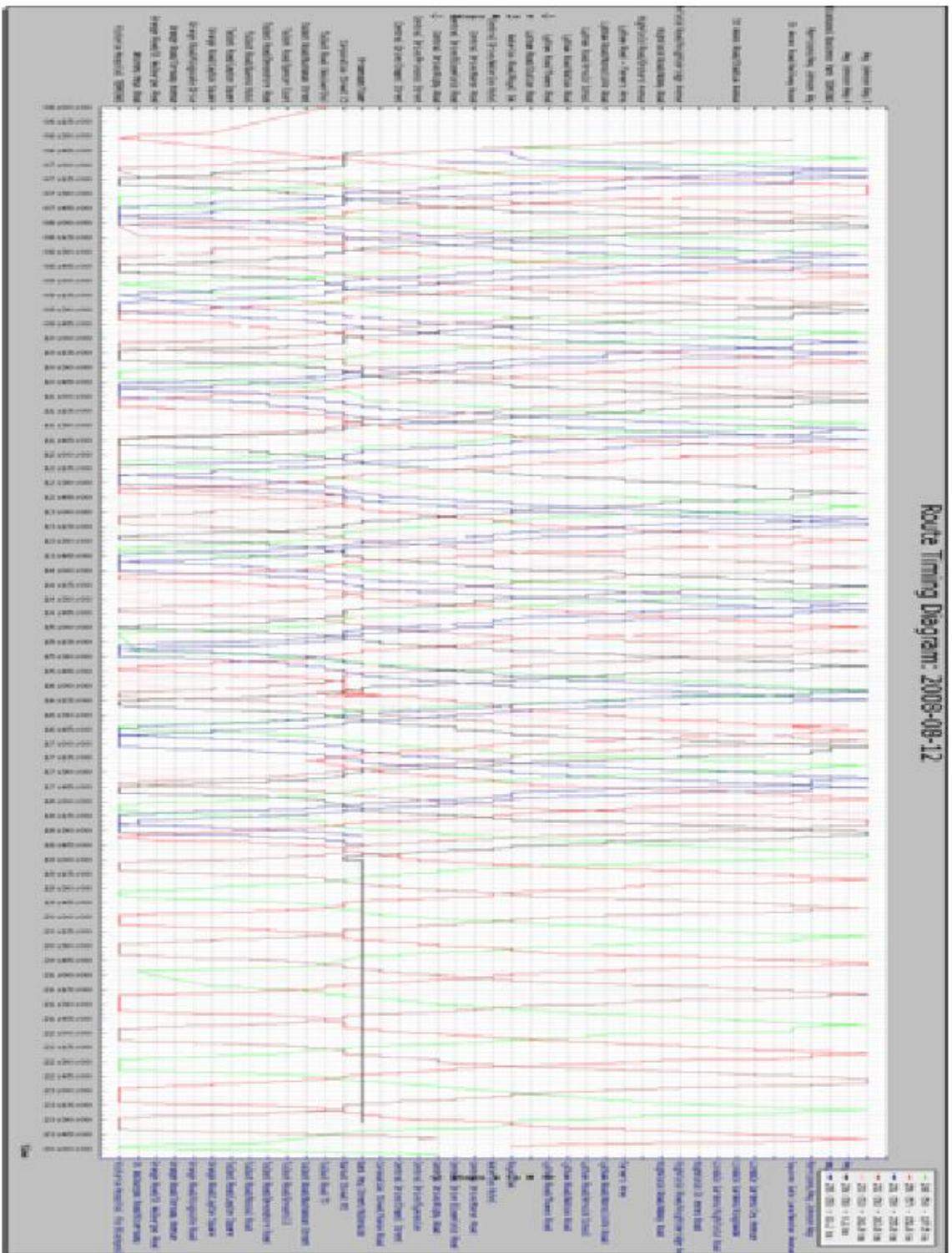


Figure 4-30 Extract of plot of bus locations, in terms of bus-stops passed, against time

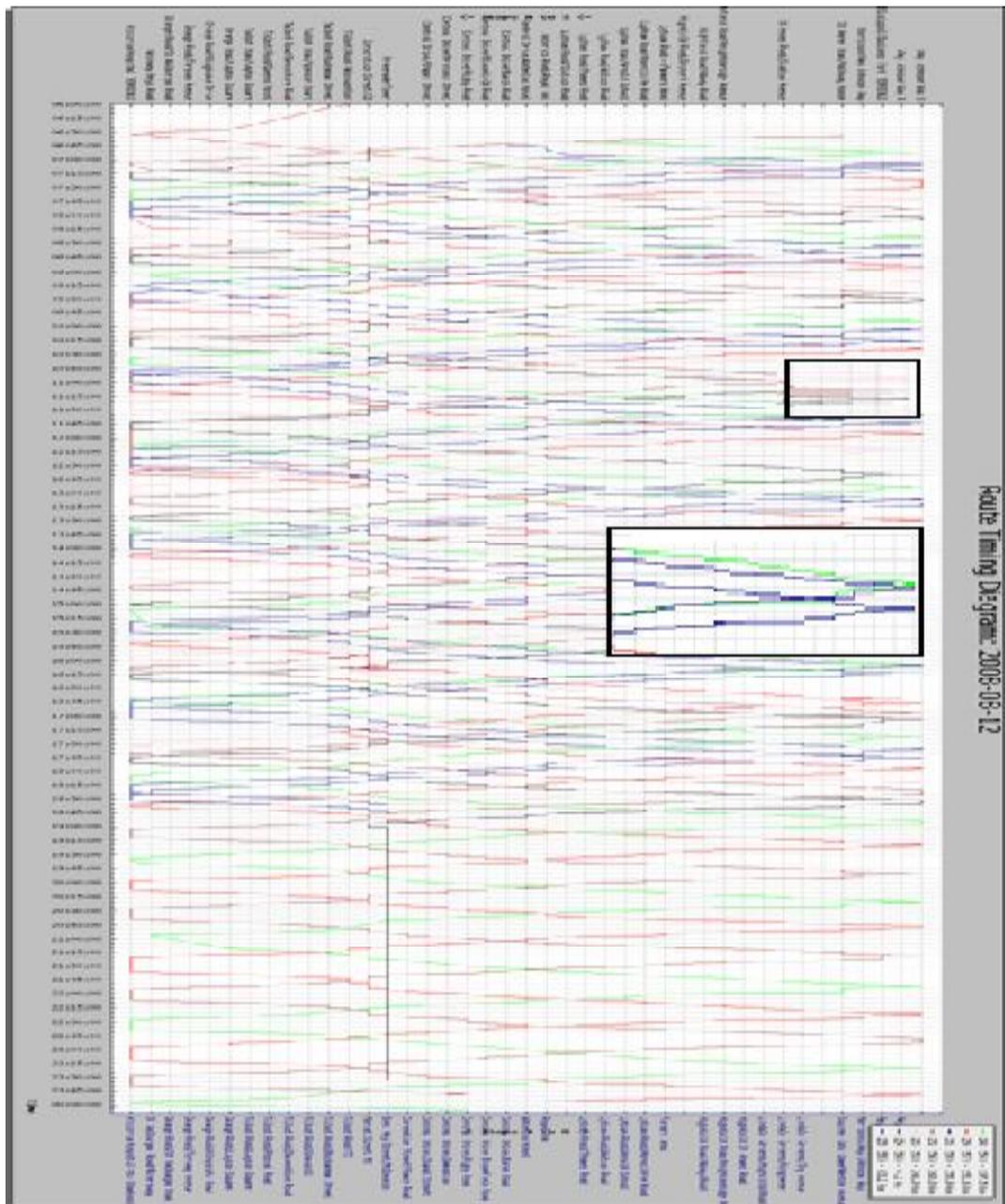


Figure 4-31 Example of bus bunching where two buses are in close proximity

Figure (4-30) and (4-31) also show the spacing of vehicles between successive trips- at any point in time and space (e.g., at each time point). This information would be difficult to identify if the data were presented in tabular format. These figures can also show the trajectories of buses in a bunch in close proximity to one another, with headways on the time axis separating different bunches of trajectories.

In Figure (4-32), the same transit data was visualised in tabular format, showing bus location in terms of the current bus stop and bus travel direction. The tabular format contains table cells to represent bus stops along the route as well as vehicle numbers. Using colour coding, when buses are close and tend to bunch at a particular point in a bus route, the system renders table cells which represent each bus's current location with an orange colour indicating the tendency to bunching. When bus bunching has happened at a particular, or near to, a bus stop, the table cell that represents that bus stop or location is rendered in red, indicating the bunching status. This can help to identify where and when bus bunching occurs. Figures (4-32) and (4-33) show the bus bunching monitoring process where the operator can detect when buses tend to bunch. This can help in a proactive process to prevent buses from bunching and maintain transit services.



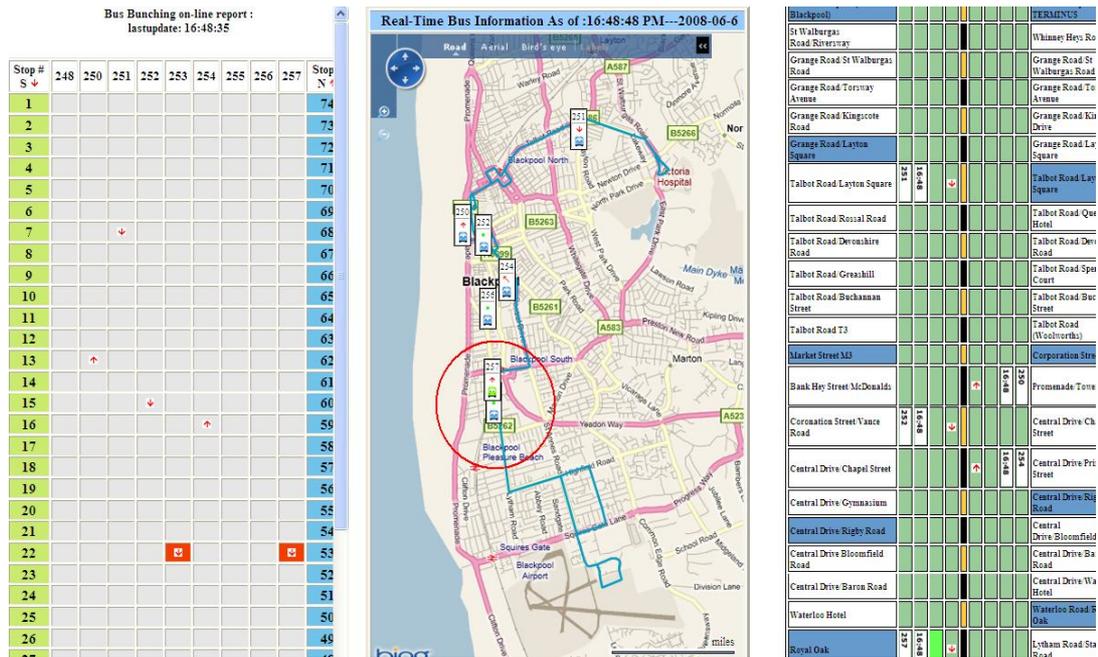


Figure 4-33 Two buses travel in a pair as a result of bunching

## 4.9 Reporting Transit Data

In software application development, reports can be a powerful tool to provide system users with information in textual or map-based format or a combination. In the transit industry, real-time (on-line) or off-line reports are essential to provide transit operators and supervisors with tools to monitor and manage their fleet (TCRP Report 113). These reports should give vital information such as vehicle details and a vehicle's current or historical behaviour. Reports can also include vehicle performance measurements and reliability indicators. These reports should be easy to use and interactive to enable users to input queries and get the information they need when they need it. Real-time reports are updated with the most recent data, so the operators know at any given time how the transit system is performing.

With real-time information, operators can determine where, why, and how potential problems might occur. For off-line reports, a vast amount of information is collected and archived for offline analysis of transit operations. This information is summarized on a regular basis in the form of performance reports that help to inform transit operators about the status of various parts of the transit system across multiple spatial and temporal dimensions. Our public transport real-time tracking system is provided with

a suite of management reports to help transit operators in improving transit system efficiency as well as the quality of service, resulting in substantial cost saving and increased transit user satisfaction. Figure (4-34) shows a real-time report that provides details of a particular transit vehicle at a given time. The generated reports include vehicle details such as timestamp, current location, vehicle speed, temperature, heading and voltage.

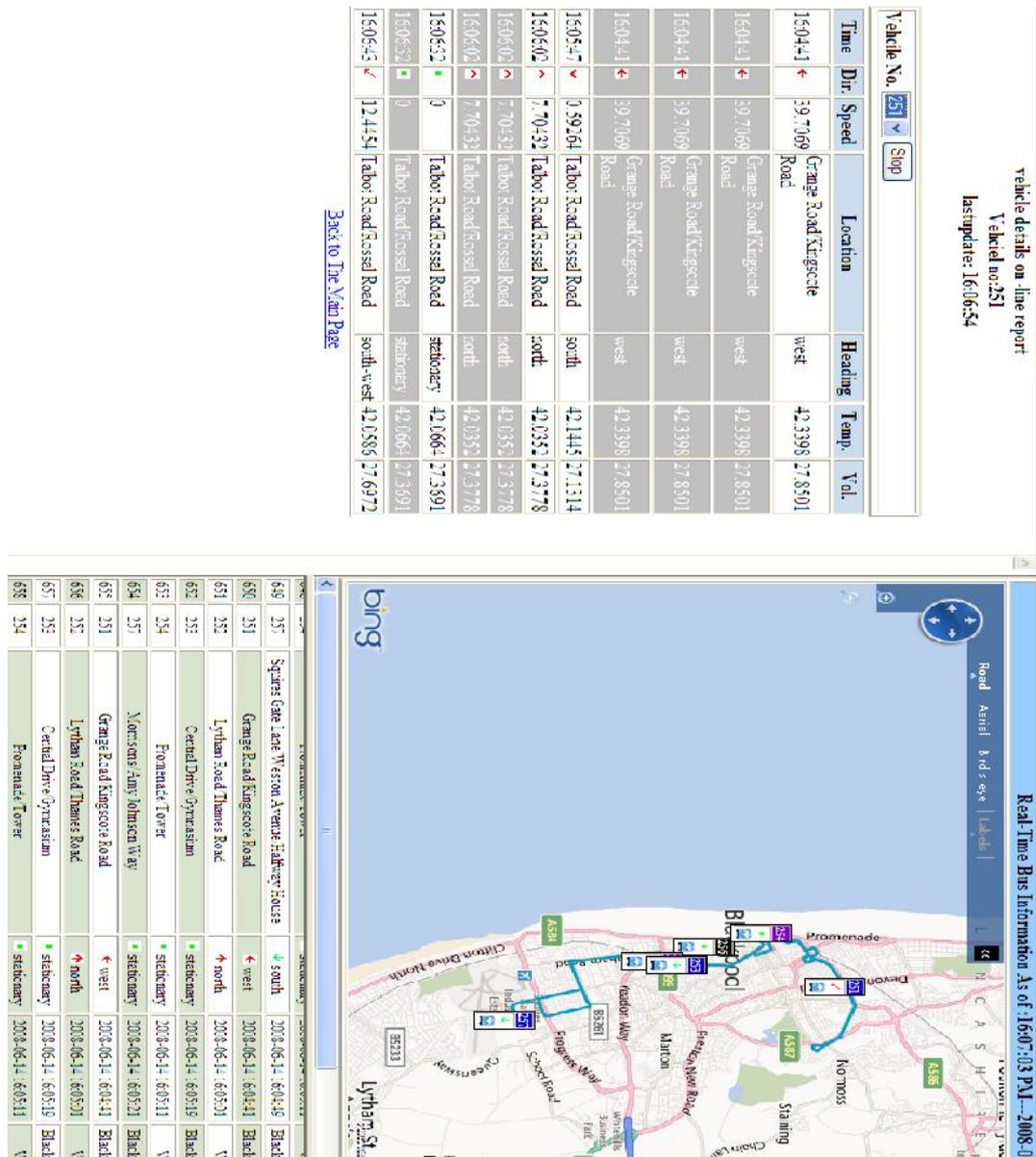


Figure 4-34 Real-time report provides details of a particular transit vehicle at a given time.

The system's ability to build an archive of transit data enables it to generate off-line reports for specific time periods; this includes off-line reports on excess waiting time, headway reliability, travel time reliability and spatio-temporal behaviour of vehicles can be shown on a map-based view or in a tabular format and other transit services reliability indices. Figure (4-35) shows the web- interface to generate off-line reports. The operator enters the date and the report required.

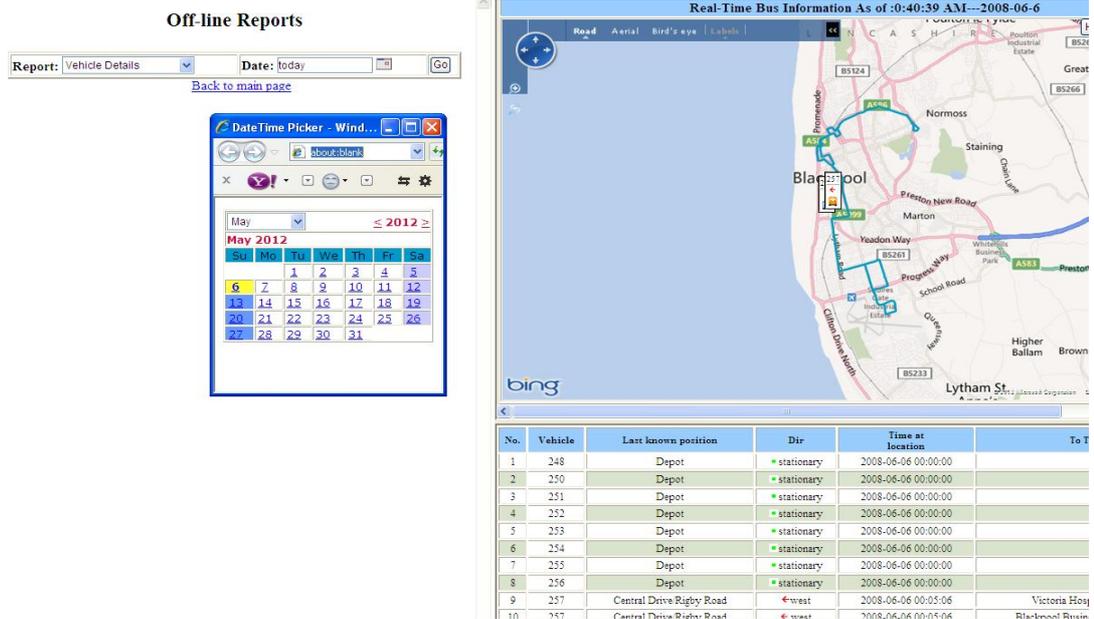


Figure 4-35 Operator interface to generate off-line reports

The vehicles' operational variables, such as speed, voltage, temperature etc., can be plotted and reported to the operator to monitor and control operational conditions. As we can see in Figure (4-36), vehicle speed as an operational variable is plotted.

Select options to plot:

Variable:

Vehicle(s):

Note: Selecting more than two vehicles may result in a data overload and an error.

From:

[Back to Main Page...](#)  
[Today's Plot](#)  
[Plot History](#)

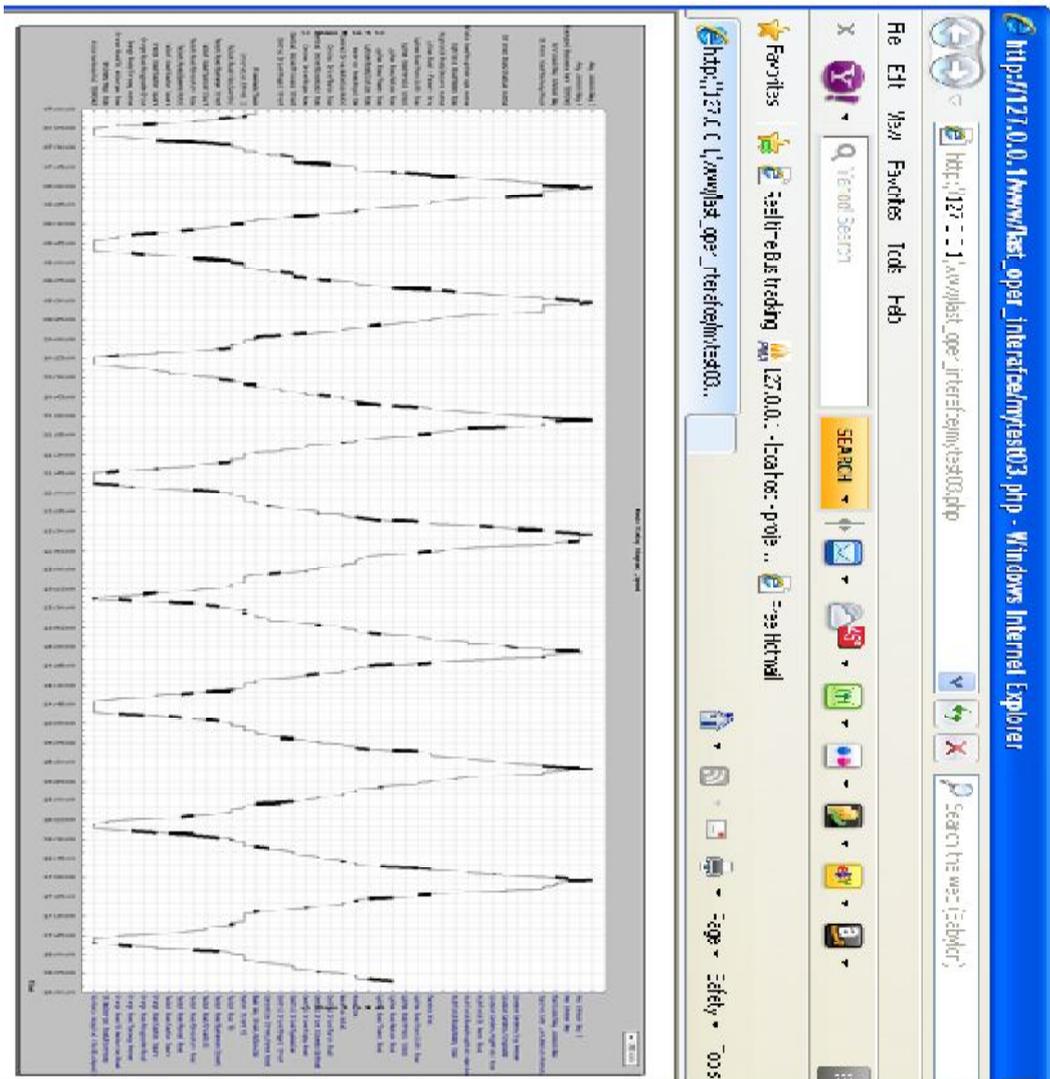


Figure 4-36 Plot of vehicle speed

Here, the operator can select the transit vehicle, the operational variable and the period of time.

## 4.10 Transit Data Playback As an Analysis Tool

Data playback may be used to help in customer complaints, incidents or accidents (TCRP Report 113). With playback tools, data from the trip in question is viewed as if it were happening in real-time. For investigating incidents, it is often helpful simply to determine whether the bus in question was there. For investigating passenger complaints, simple playback of the recorded GPS information can identify whether a bus was very early or late, or off route. GPS data can also be used to investigate operator overtime claims. Figure (4-37) illustrates the data playback interface. On this interface the transit operator can select the date and the system playback transit data and show it on a table and transit map.

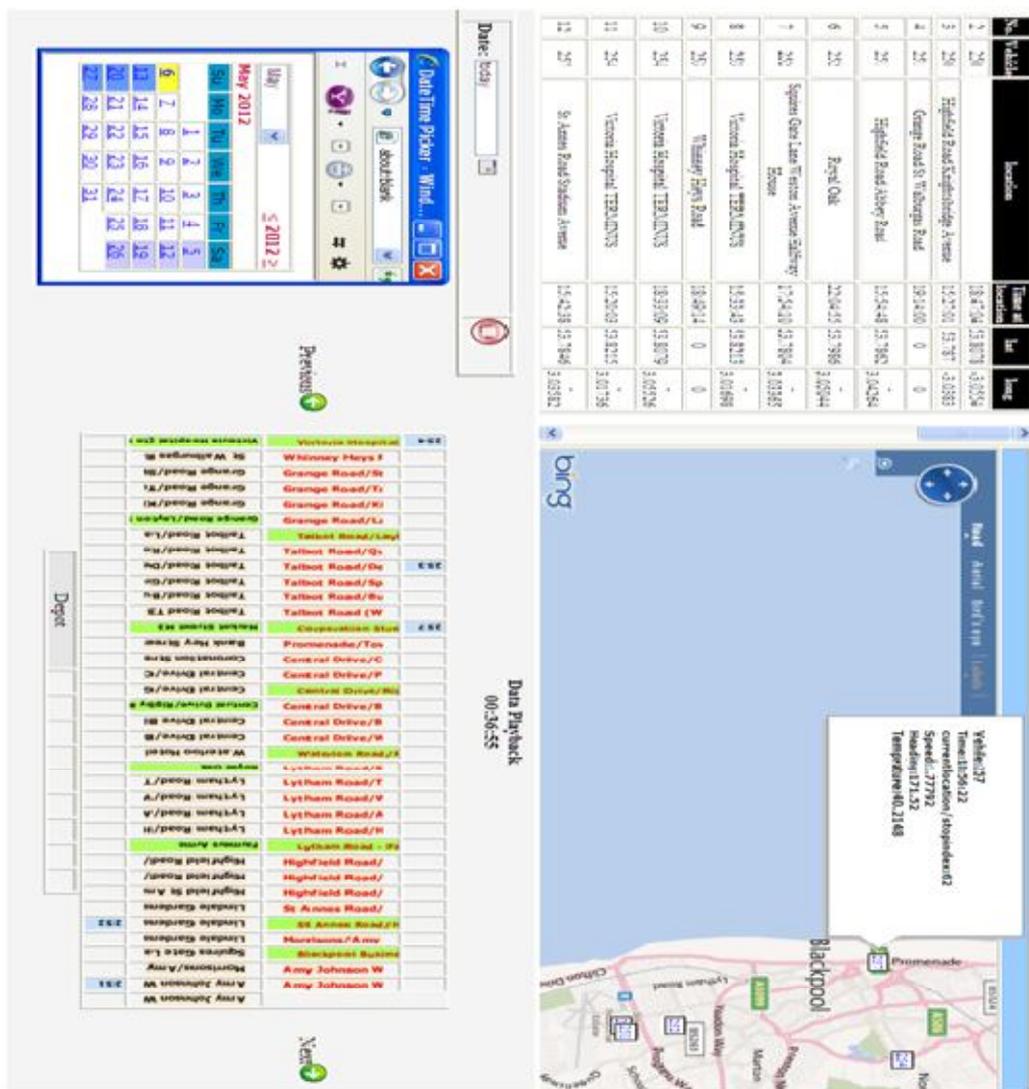


Figure 4-37 Transit data playback interface

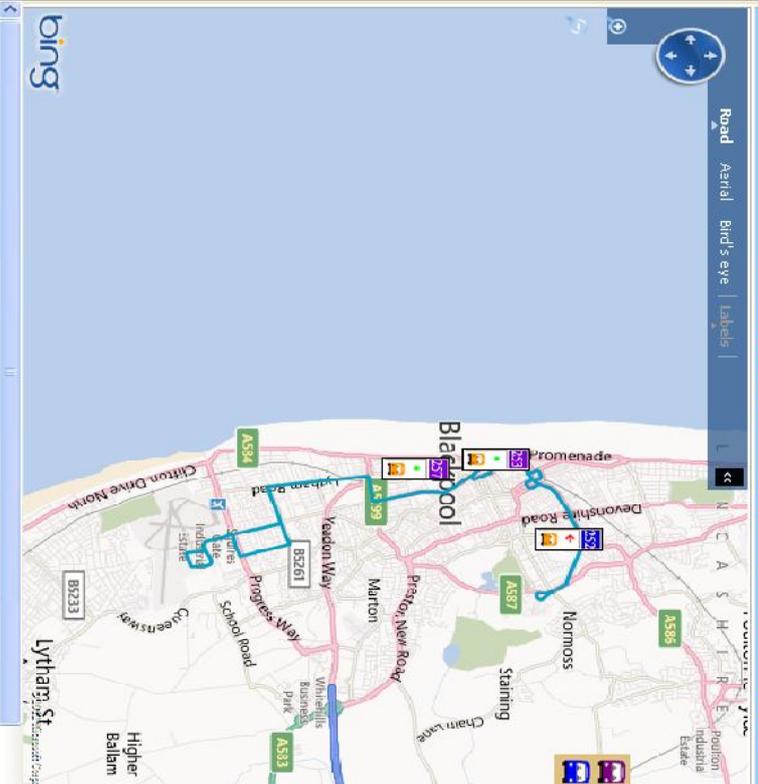
### ***4.11 Monitoring Safety and Improving Emergency Response for Transit Vehicles***

Recent improvements in video data recording systems make them a viable option for monitoring transit vehicle performance. These systems can provide video recordings and vehicle data in the event of safety-related accidents or violations. A series of small cameras can be installed on the interior of the bus to record the interior views and the roadway ahead. Along with transit vehicle details, real-time images can be transmitted to a central server where transit operators or supervisors can identify vehicle location for immediate response to any safety-related event. To demonstrate safety- monitoring concepts of real-time bus tracking systems we created a street view image (Google maps, 2012) of the transit vehicle's current location and send that to the transit operator for monitoring in a real-time environment. Figure (4-38) shows street view images for a transit vehicle's current location. The system updates these images in real-time and they are transmitted periodically to a central server.

248 00:00:00	250 00:00:00	251 00:00:00
NO IMAGE AVAILABLE	NO IMAGE AVAILABLE	NO IMAGE AVAILABLE
252 21:11:00	253 21:11:00	254 00:00:00
		NO IMAGE AVAILABLE
255 00:00:00	256 00:00:00	257 00:00:00
NO IMAGE AVAILABLE	NO IMAGE AVAILABLE	NO IMAGE AVAILABLE

[Back to The Main Page](#)

**Real-Time Bus Information As of: 21:12:36 PM --- 2008-06-14**



Road Aerial Bird's eye Labels

No.	Vehicle	Last known position	Dir	Time at location	To Term
1	248	Depot	stationary	2008-06-14 00:00:00	-
2	250	Depot	stationary	2008-06-14 00:00:00	-
3	251	Depot	stationary	2008-06-14 18:44:00	-
4	252	Grange Road Turnway Avenue	stationary	2008-06-14 21:10:05	Blackpool Business F
5	253	Corporation Street C3	North	2008-06-14 21:09:45	Victoria Hospital
6	254	Depot	stationary	2008-06-14 19:59:53	-
7	255	Depot	stationary	2008-06-14 00:00:00	-
8	256	Depot	stationary	2008-06-14 00:00:00	-
9	257	Depot	stationary	2008-06-14 18:57:04	-
10	252	Grange Road Kearsdale Drive	stationary	2008-06-14 21:10:56	Victoria Hospital

Figure 4-38 Street view images for a transit vehicle's current location

## ***4.12 Modelling Passenger-flow in a Real-Time Bus Tracking System***

Modelling passenger flow in real-time environment can be an effective tool to measure the movement of passengers within the transit system and see how the actual performance of transit vehicles impact on passengers. The existence of similarities between a public transport system network and other networks such as computer data networks may be encouraging for the modelling process. Transit networks in the real world are similar to data transfer across a computer network. Most computer networks can be viewed as transportation infrastructures for the deployment of data. In general, there are some similarities and differences between bus and computer networks in terms of moving objects, transfer mechanisms, and monitoring procedures where the primary aim of both networks is to move units/elements from an origin to a destination as quickly as possible with no (or at least minimal) negative impact. For modelling the passenger flow, the bus stops and routes can be modelled as a network of nodes in a communication system with passengers moving like data around the network. However, before explaining the modelling process in detail we need to investigate a little more about computer networks, transit networks, and the similarities and differences between them.

### ***4.12.1 Computer Networks and Public Transport Networks: Similarity and Differences***

Over the last twenty years, the field of computer networks has grown from simple to more advanced communication techniques (Stuart, C., et al., 2010). The basic method used by computer networks is sending ‘packets’ of data through the connection media. This media consists of cables with hubs, switches and routers providing connections between the origins and destinations within the network. Most data networks operate on the concept of ‘best effort delivery’, where the network does not provide any guarantee that the data is delivered; nor is a user given a guaranteed quality of service level or a guaranteed priority (Tittel, Ed.,2002). As in public transport networks, in a best effort network all users (passengers) obtain best effort services: they obtain an unspecified variable bit rate and delivery time depending on the current load. In computer networks, when a packet arrives at a

router, routing algorithms make an on-the-fly decision and select to which adjacent node the packet should be sent. These route decision-making protocols running in the routers use the information gathered about the network topology (Tanenbaum, A.S., 2002). The algorithms in route decision protocols become more and more complicated as the network grows. Computer networks provide congestion control using the Transmission Control Protocol (TCP). When the network is congested, packets are lost or 'dropped' (Hekma, S. 2005). Packet loss is normal in network operation and is not seen as a failure of the network. Lost packets can be retransmitted using an acknowledgment technique. When the network is congested, the sender (router) reduces the rate at which data is sent, as the packet loss was caused by the network congestion. Therefore, as in road networks, techniques and procedures are used to monitor and control the movement of packets through the network.

Public transport networks can be seen as networks of roads, streets, stops or any structure which permits either vehicular movement or the flow of some commodity. Transportation networks can be classified based on the different categories such as operational area (urban or rural networks) or service type (fixed route service or paratransit service). Instead of packets, both vehicles and passengers can be considered as moving objects through the networks and the roads represent the main media on which vehicles are transported. People (passengers) are transported on roads either in individual cars or automobiles or in mass transit/public transport by bus/coach (vehicle). In transportation networks, a road is defined as a one/return way loop that connects a sequence of geographical points called stops and terminals where passengers can board and alight. Many factors, such as road length, number of stops and distance between stops, can affect a transportation network's structure (Yong-Zhou, C. et al., 2007). During a bus journey, passengers go through different stages such as waiting, queuing and transferring from the origin point to the final destination. These different stages are affected by services provided and the transportation network resources.

There is sufficient similarity between computer networks and public transport systems to an extent that it is valid to make a comparison between them. In transportation networks, passengers are served individually, as in data networks

that divide data into small blocks (packets), which they send individually. The store-and-forward process where the packet is stored until it fully arrives, then is forwarded to the next router along the path until it reaches the destination host where it is delivered (Hekma, S. 2005). This process is used in networks so passengers like packets are waiting and queuing at bus stops/switches until they are transferred to the next point/node. Both passengers and packets are impacted by the network's performance, such as delays and transmission rate. The movable units within a transport network are self-aware: that is, they choose their route/destination and control the timing of the trip. On the other hand, data packets have no self-awareness and do not choose their origin/destination, nor do they choose their route. Propagation delay exists in both networks.

In computer networks, delay caused by packets that pass through routers and switches due to software requirements need these devices to perform their function. In transportation networks, delay caused by increased traffic demand may approach the capacity of a road, causing a traffic jam. The two networks handle congestion in different ways. While there are many instances where data packets are lost, this cannot be adopted for the travelling elements of a transportation network. The best-effort delivery system cannot be adopted in a transportation network, so it is reasonable therefore to think that instated the end-to-end route algorithms of computer networks could be applied in transportation networks (Stuart, C., et al., 2010). For managing the traffic in transportation networks, the hold-and-express algorithm is used, and on the other hand, in computer networks, the store-and-forward algorithm is used to control data flow. The similarities of functionality of both networks in moving units from origin to destination points suggest and encourage the adoption of techniques and algorithms used in computer networks to model passenger flow through transportation networks.

#### *4.12.2 Computer Network Performance Indicators Matching with Performance Indicators of Transport Networks*

Most of a computer network's performance can be measured qualitatively and quantitatively. Several measures are used to evaluate a network's performance, including:

- *Delay*

Delay refers to ‘how long it takes for a bit of data to travel across the network from one computer to another’ (Douglas, E. (2007). Delay is measured in seconds or in fractions of seconds. Delays may differ slightly, depending on the location of the specific pair of computers that communicate. The data packets within computer networks face different types of delay, which affects the overall performance. These types of delay are processing delays caused by node processing, queuing delay caused by the buffering of packets at the station, and transmission delay caused by media bandwidth. Travel time in transit networks can be a road analogy for delay in computer networks.

- *Throughput*

Throughput is the rate at which data can be sent through the network, and is usually specified in bits per seconds (bps). The throughput capability of the underlying hardware is called bandwidth. In transit networks, throughput is represented by the average quantity of passengers that can pass through a station on a daily basis from arrival at the station to loading on a bus.

- *Delay-Throughput product*

Delay-throughput product is the volume of data that can be present on a network. If we think of the road analogy: when cars are entering a road at a fixed rate of  $T$  cars per second and it take a car  $D$  seconds to traverse the road,  $T*D$  additional cars will enter the road by the time the first car has made its complete trip.

- *Jitter*

In high-speed digital communications, jitter is the variance of the delay on the network. Jitter can also be defined as the variation (i.e., standard deviation) in packet arrival times. Controlling jitter in the digital signal path plays a very important role in minimizing bit error rate and thereby increasing system reliability. In transport networks, jitter can be interpreted as the standard deviation of passenger arrival times.

As we explained in Chapter 3 Section (3.10) and in this chapter Section (4.6), Quality of Service or QoS is one of the common metrics used for public transit

performance evaluation. After our review of the similarities and the differences between computer networks and transport networks, we will explain a simulation model to evaluate transit vehicle performance and analyse the overall performance of the network and enable the operators to fix and maintain any problems that occur.

#### *4.12.3 A Simulation Model and Experiments*

There are diverse methods and tools aimed to support public transport operators regarding routes, timetables and vehicle schedules. This set includes passenger surveys, land-use models, field tests, heuristics, operations research techniques and computer simulations. Computer simulations offer a feasible, flexible and attractive tool for planning and analysing transit systems. Transit simulations may serve several interests (Meignan et al., 2007): global observation of the network to check its functioning and design; evaluation and control of dynamic processes (e.g. transfer synchronization); evaluation of the network efficiency using various measures for different alternatives (e.g. routes or frequencies). In order to adequately analyse and evaluate the performance of real-time transit systems, it is essential to model dynamically the interaction between passenger demands and transit operations. Transit simulations provide a dynamic perspective on transit operations, enabling representations of complex interactions between the transit system components; transit vehicles, passengers, and transit operations. Service reliability is one of the main factors determining transit system level of service, as unreliable service results in longer waiting times, uneven passengers loads and missed transfers. There are several sources of variability that contribute to service unreliability, including variability in arrival/departure times to/from bus stops, dwell time and riding times. Studying the effect of transit operations on passengers is difficult because of interrelated stochastic process involved. Many studies in this area assumed a constant passenger arrival rate and neglected transit vehicle capacity. A simulation-based evaluation model of real-time transit services was developed to improve service reliability and enable the representation of large scale transit systems (Shalaik, B. et al, 2012b). This model is used to evaluate a real-time transit system in a real-world bus line in Blackpool city under various scenarios.

Our simulation model, like all models, requires a set of input data and generates output data. The model is stochastic where different runs with the input data will generate different output results. The model requires transit-related data in order to simulate the public transport system. This input includes:

- 1- Routes: every transit vehicle is assigned to a unique route which serves a sequence of stops. Bus route information is derived from our real-time bus tracking system.
- 2- Timetables: the service schedule is published to the passengers and presents the expected arrival/departure time for each bus trip in each bus stop.
- 3- Demand: Passenger demand, which determines the alighting and boarding, is represented by two components: the demand to get on and the demand to get off each bus at each stop. On high frequency routes passengers arrive randomly at bus stops (Ronghui L., and Shalini, 2007) and in the simulation process random numbers were generated to reflect this. The passengers demand varies by one variable (the bus stop type). If bus stop is a high demand one, the generated number of passengers should be higher than when the stop is a regular stop.
- 4- Characteristics – Transit vehicles and bus stops have special characteristics that influence transit operations. Features, such as bus capacity are important for a transit service and so we assume that maximum bus capacity is 50 passengers. Regarding the type of bus stop, there are regular bus stops and time point bus stops

The transit simulation model reported in this thesis is transit operations oriented and therefore focuses more on the supply side than on the demand side. Transit vehicles move between bus stops within the network of public transport, these vehicles arrive at the stops at different times dropping off and loading passengers. Elements of the behaviour of these vehicles that are modelled include; generation of vehicles based

on schedules, behaviour at stops, and a detailed representation of passenger demand at the various stops. Every transit analysis tool has to assume some characteristics (function, distribution) on the transit service mechanisms; boarding, and alighting processes, running times, departure and delay times. The basic attributes of transit operation as travel time, boarding, and alighting processes are crucial for any model that intends to represent transit operations. These assumptions are in the core of every model because they dictate the measures of service (e.g. passenger waiting times (Bowman and Turnquist, 1981). The movement of the buses is derived from our real-time bus tracking system. The simulation model interface is shown in Figure (4-39). A record is generated every time a transit vehicle exits a bus stop. Every record includes stop ID, Vehicle no, arrival time, scheduled time, waiting passengers, boarding passengers, alighting passengers, occupancy, and passengers left behind.



Figure 4-39 Simulation model interface

By modelling the passenger flow and measuring transit vehicle performance indicators, we can analyse the overall performance of the network and enable the operators to fix and maintain any problem that could occur. Passengers take a certain amount of time at bus stops waiting for the next bus, or queuing for boarding and

alighting (Rodrigo, .F and Nick, T., 2005). This time is called Passenger Service Time (PST) and it is a function of the number of passengers. The simulation model was developed to allow visualising what would happen at a transportation network under a variety of operating conditions. The aim of this model is to analyse the overall results of passenger service time due to changes to certain bus operational factors. The same set of variables and parameters were used for all the experiments. The initial conditions assumed the following:

- 1) Buses carry passengers up to their capacity,
- 2) Other passengers are waiting at bus stops, and
- 3) Buses are running according to their planned timetable and headways.

The proposed simulation model can run different experiments with different scenarios that simulate passenger flow in a real-world environment with disruptions such as trip delays, miss-connection or cancellation of buses along a route. There are three different levels or stages where passengers can be affected by transit services. These stages are the origin-point stage, boarding stage and arrival stage.

- ***Origin-point stage***

The origin point stage is where the passengers wait for the next bus, with the possibility of deviation from the advertised timetable (delayed or ahead). At this stage, passengers might have to wait longer than the expected time (Excess Waiting Time) due to irregular headway or a bus that fails to run. When a bus arrives at a bus stop, there is a possibility that some or all passengers cannot board because of the bus's limited capacity, and this will have a negative impact on their travelling time, causing more delay and increasing waiting time at other bus stops.

- ***Boarding stage***

The boarding stage is the stage where the PST is a function of passenger demand. The boarding passengers' wait-time must include an allowance for passengers on the bus to alight.

- ***Arrival stage***

The arrival stage is the stage where passengers reach their final destination. Their

arrival can be on time, ahead or delayed depending on the deviation from the timetable.

#### *4.12.4 Results and Analysis*

In an ideal environment, the passengers at a bus stop wait for their bus to arrive, the bus arrives on time, and then allows some passengers (demanding passengers) on board to alight and other passengers (boarding passengers) at the bus stop to board the bus respectively. This scenario is repeated at all bus stops until the bus reaches its final destination. Due to different factors such as traffic, road and weather conditions or passenger demand, a bus can get delayed and deviate from the planned timetable and headway, and thus waiting or onboard passengers all along the bus route will be affected by this delay or deviation. The simulation model is designed to generate output such as in Figure (4-40). Figure (4-40) illustrates passenger-flow simulation output

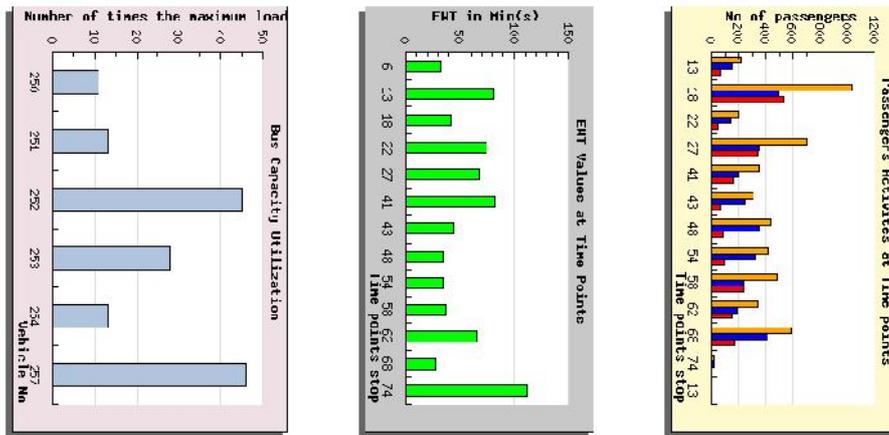
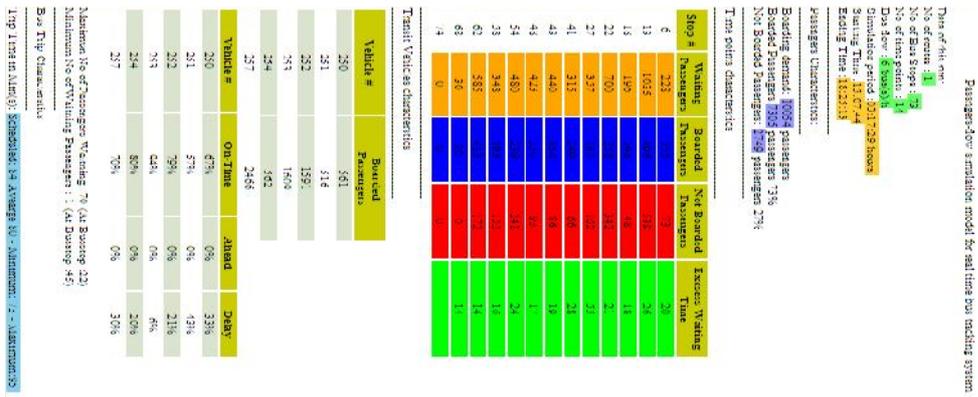


Figure 4-40 Passenger-flow simulation output of the real-time bus tracking system

From the simulations, the output transit network works with full capacity and buses are following the timetable, but there are some deviations, as shown in Figure (4-40). Out of the overall demand, 80% of passengers boarded on time and 20 % had to wait for the next bus. It seems that 59 % of passengers will arrive on-time and 41 % might be delayed. Buses seem to be running on their scheduled time: that is, 84 minutes. The average running time was 80 minutes while the shortest duration of the trip was

73 minutes and the longest was 95 minutes. We can generate random numbers to represent the number of passenger who are waiting at bus stops and then simulate transit system operations in real time including the boarding and disembarking process of buses and measuring the performance of the transit system.

### ***4.13 Conclusion***

Public transport operators are increasingly realising the benefits of collecting and analysing operational data recorded by AVL systems, and using it to improve the quality of their service. This chapter introduced new techniques to monitor, measure and analyse transit system operations. In this chapter we discussed Quality of Service metrics and the importance of measuring these metrics. Data visualisation techniques and calculation of metrics were implemented to quantify and measure public transport service reliability for a public transport system. Using available data collected from Blackpool bus route 5 combined with a set of observations, measures of reliability and their variability were calculated. We discussed the use of AVLS to collect transit data and build an archive to generate on-line and off-line reports. We described tools to measure and depict transport network reliability at a more detailed level using AVLS data. Direct causes of unreliability along the line can be identified, and a clearer picture of how the transport system works can be drawn. A simulation-based evaluation model was developed to measure factors that affect passenger trip time and estimate the transport network to serve passenger demands. The provision of efficient tools for the transit operators may help to improve the performance of the transport system and also help to provide better transit services for passengers. In the next chapter, we will discuss models and techniques that enable passengers to easily interact with public transport systems and extract the desired information.

## **Chapter 5 Interactive Public Transport Systems**

### ***5.1 Introduction***

In the early stages of the use of Automatic Vehicle Location Systems (AVL) in transportation, the focus was on using them to increase operational efficiency, rather than to provide passengers with transit information (TCRP Synthesis 48, 2003). With the increased use of these systems, transit operators realized that data from the AVL systems can also be used to provide passengers with real-time information (TCRP Synthesis 48, 2003). Transit information is not only provided at the bus stop, by means of an electronic display: it can also be provided in a variety of other formats such as HyperText Markup Language (HTML) and Extensible Markup Language (XML) (XML, 2012) for Internet applications, and Wireless Markup Language (WML) for Wireless Application Protocol devices, such as mobile phones, and Personal Digital Assistants (PDAs).

In this chapter we introduce models and techniques that enable passengers to easily interact with public transport systems and extract the desired information. Transit information must be available in different spatio-temporal contexts, such that passengers can receive this information at home, at work or at the roadside. We also discuss Location Based Service concepts (LBS) and its potential to improve transit information. We show how to integrate our real-time bus tracking system with a pedestrian navigation system to provide door-to-door real-time transit information

### ***5.2 The Dynamic Provision of Transit Information***

Passengers are constantly worried about their trips while using public transport systems (Brendan N. et al, 2004). Bus delays, route changes and confused schedules are just a few of the concerns that passengers may have during their travel. In public transport systems, a journey begins with planning the trip, finding the nearest location to board the bus, finding the time the bus should arrive, waiting at the bus stop, payment before the journey, in-journey activity, alighting from the bus and finally moving to the destination. This process has been discussed by many authors (Edison et al. 2011; Kristoffersen and Ljungberg 1998).

When passengers use public transit systems, they require different types of information throughout their journey; this information may include:

- Pre-trip information which focuses on planning services such as stops, stations and the services available (e.g. buses, trains, trams, etc.) and accurate arrival times for service vehicles. Pre-trip information can be static or real-time. Static pre-trip information is based on timetables and maps to provide information, which may become obsolete when route or timetable changes occur. However, real-time information is obtained from the actual execution of buses.
- Bus stop information is provided at bus stops to enable passengers waiting for buses to determine which bus to board. Bus stop information can be static through timetables, route numbers or posted maps. Static information is essential for any bus stop. Dynamic information is highly desirable, an ideal timetable shows times that a bus will arrive, transit times to all stops and details each route that services this stop.
- In-vehicle information systems provide information such as the expected time of arrival at destination stops and alerts for when the user is arriving at the destination stop and if they are required to transfer to complete their trip. In-vehicle information can also be classified as static or real-time. Static information is delivered through timetables or maps. Real-time information can be delivered via variable message boards on buses and announcements; also, dynamic light maps can be used to inform passengers about their location.
- Guidance to the user's actual destination from the destination stop can be achieved via a pedestrian navigation system. There are two stages in the trip where the user needs pedestrian navigation assistance. The first stage is getting from their original location to the original bus stop and then from the final bus destination to the actual user destination. This information is also important as it reduces the total trip time.

Table 5-1 Types of transit information and their purpose

Information Type	Purpose
Pre-trip	Route planning Available Services
Transit Stop	Anxiety relief Route information Real-time Arrival Delay formation
In-vehicle	Current location Transfer information
Pedestrian navigation	Arriving at actual destination

Table 5-1 shows the type of information required and purpose for providing this information. The provision of transit information throughout these stages would create a complete end-to-end journey planning and assistance system.

The lack of information at bus stops can make wait times unbearable. At the bus stop, passengers need to know whether the coming buses serve the route they want to follow, which adds more anxiety. After boarding the bus, passengers must determine when to alight and if any transfers are required, and what is the best walking route to reach their final destination. These factors may make travel by bus a stressful and unpleasant experience. Real-time bus tracking and the provision of transit information at stops can dramatically improve transit services, such increased information can make a journey more enjoyable, which improves the perception of public transport systems.

### ***5.3 Current Interaction Models for Passengers***

Transit information is no longer provided through printed-paper only. Today, many transit agencies in developed countries, regardless of their size, make transit information such as bus schedules and/or real-time data available on the web in one

form or another. Mobile phones are also used to provide passengers with transit information. Tools on the web and mobile devices are increasingly being developed to enhance public transport system usability and improve the interaction between these systems and their passengers (B. Ferris. et al.,2011). The option of accessing transit information from multiple sources offers many options for effective interaction with transit services at the user’s convenience. Passengers prefer to derive information from different sources, such as the internet, call centers, mobile devices at the bus stop or real-time information displays across different stages of a public transport trip (Caulfield, B. and O’Mahony, M. 2007).

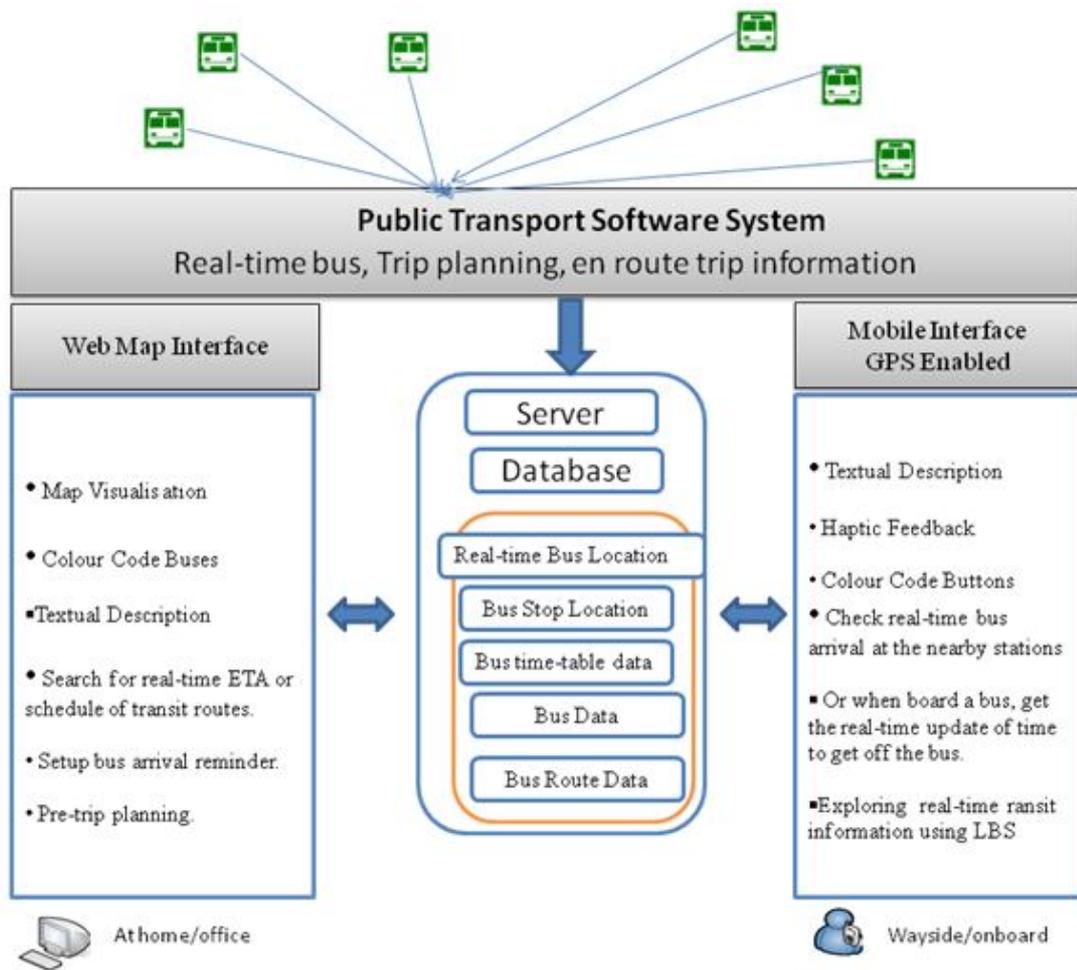


Figure 5-1 Web and mobile interaction models with a public transport system

As shown in Figure (5-1), passengers can access transit information in a variety of formats through web-based or mobile-based interfaces. Each format needs to be utilised carefully so the user can get the information effectively. Our public transport

software system provides various tools and modes of interaction to access transit information effectively. These are described in the next sections.

### *5.3.1 Web-Based Interaction*

The web is a suitable medium for delivering transit information: it has the potential to reach a large audience with transit information at a low cost. Transit information can also be accessed at any time. The Web interface is ideal for quickly retrieving information; however, it needs more attention in terms of design. Interface design concerns are related to the presentation and interaction of the data to the end-user. For real-time transit vehicle systems, the user interface should enable complete navigation of the transit region map via a variety of interactive gestures and tools. Features including arrival time prediction information, alarm notifications for selectable bus stop and searching for a particular bus stop, transit vehicle or point of interest are valuable tools in allowing passengers to make better travel decisions (Stuart D. M. and Daniel J. D., 2001).

Map-based representations of transit data assist in understanding and visualising of transportation information. Map-based representations combined with web service technologies such as AJAX (Zepeda J.S. and Chapa,S.V. 2007) are particularly well suited to real-time updates. The user is not required to interact with the map interfaces to retrieve updates: these updates to the map content can happen automatically on the browser. Icons on a map can be used to represent vehicles and these icons can move automatically, with no action required by the user, representing the last-known locations of a vehicle.

The proliferation of web map Application Programming Interfaces (API), such as OpenStreetMap (OpenStreetMap, 2012), Google Maps (Google Maps, 2012) and Bing Maps (Bing Maps, 2012) allows developers to overlay and combine data from different sources and make it appear on top of interactive maps. This can be useful to application developers for developing real-time transit information systems allowing transit data such as bus routes, bus stop locations and transit vehicles' current locations to be shown on a map.

Figure (5-2) shows the architecture of a web-based display of a real-time vehicle tracking system. In Figure (5-2) the web interface may involve XHTML, Cascading

Style Sheets (CSS) and a Document Object Model (DOM). The XHTML has the content of the page through tags. CSS offers the separation of content and presentation in the page through style documents with the elimination of redundancy. The CSS rules are in different files to achieve the separation. The DOM specification contains the way of dynamic access and the updating of the content, structure, style, and elements of a page. The application sends a request to change the content, and depending on the browser the request the applications creates is sent. For example, Internet explorer uses a special class called ActiveXObject, while Firefox and Safari use the XMLHttpRequest object.

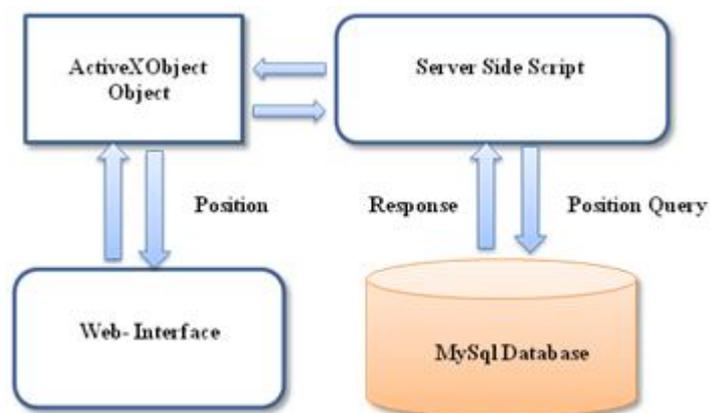


Figure 5-2 The real-time web-based display of a vehicle tracking system for internet explorer only

The request is sent through the HTTP protocol and processed at the server-side. The database returns new data to the web from the application, using a combination of the the DOM and CSS the new data is added and the web interface updated. Public transport systems such as BusView (Stuart D. M. and Daniel J. D., 2001), OneBusAway (B. Ferris., Kari, W. and Alan, B. 2010), NextBus (NextBus, 2012) offer web-based user interaction for their passengers to interact with the transport system.

In our public transport software system, we have developed a public interface whose primary view is a Bing map from Microsoft, which shows and updates vehicle

locations in a close to real-time environment. Passengers can browse the map directly to see transit stops at a particular location. Passengers can switch between bus routes and display transit vehicles for each route. We calculate the direction of travel for buses and show a directional arrow for the vehicle on the map. This direction-of-travel-arrow is particularly useful to passengers for differentiating between transit vehicles. Figures (5-3) and (5-4) show the public interfaces of transport system.

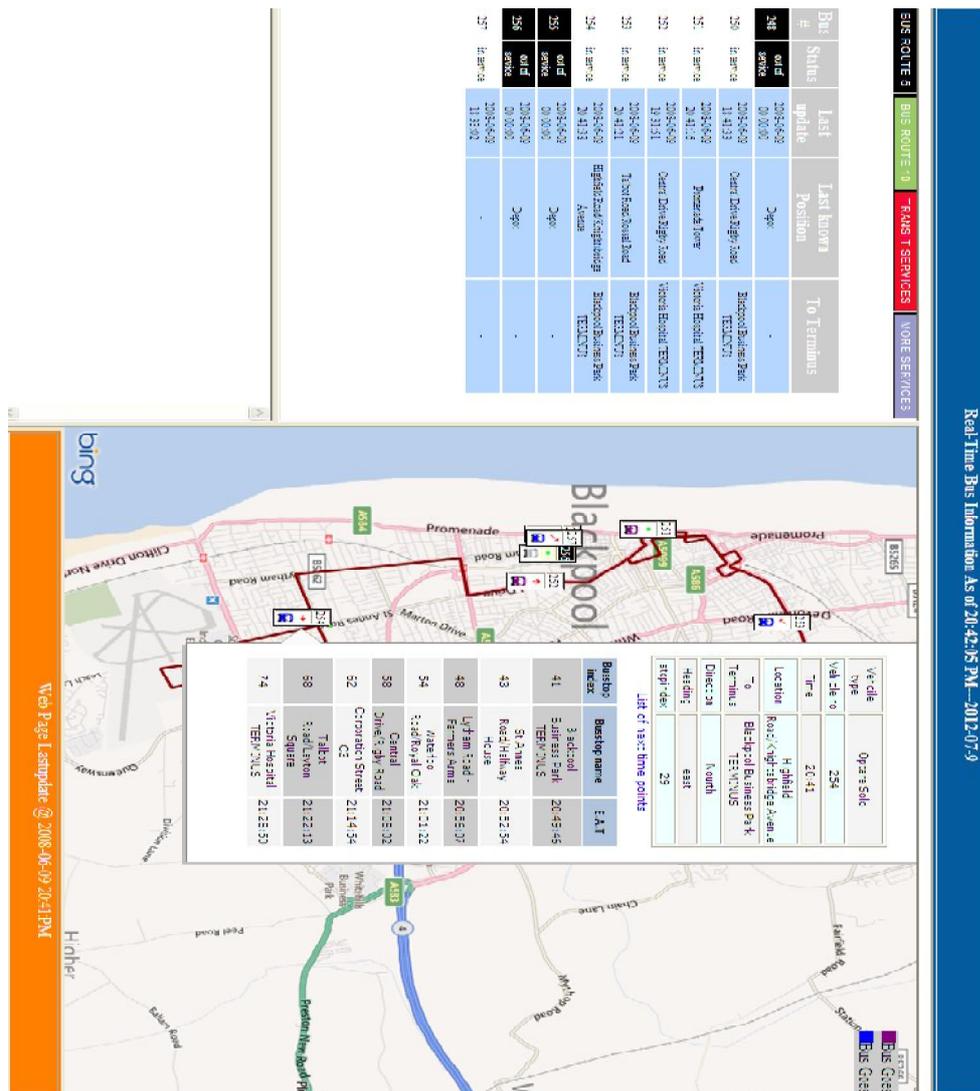


Figure 5-3 Public passenger interface of transport system

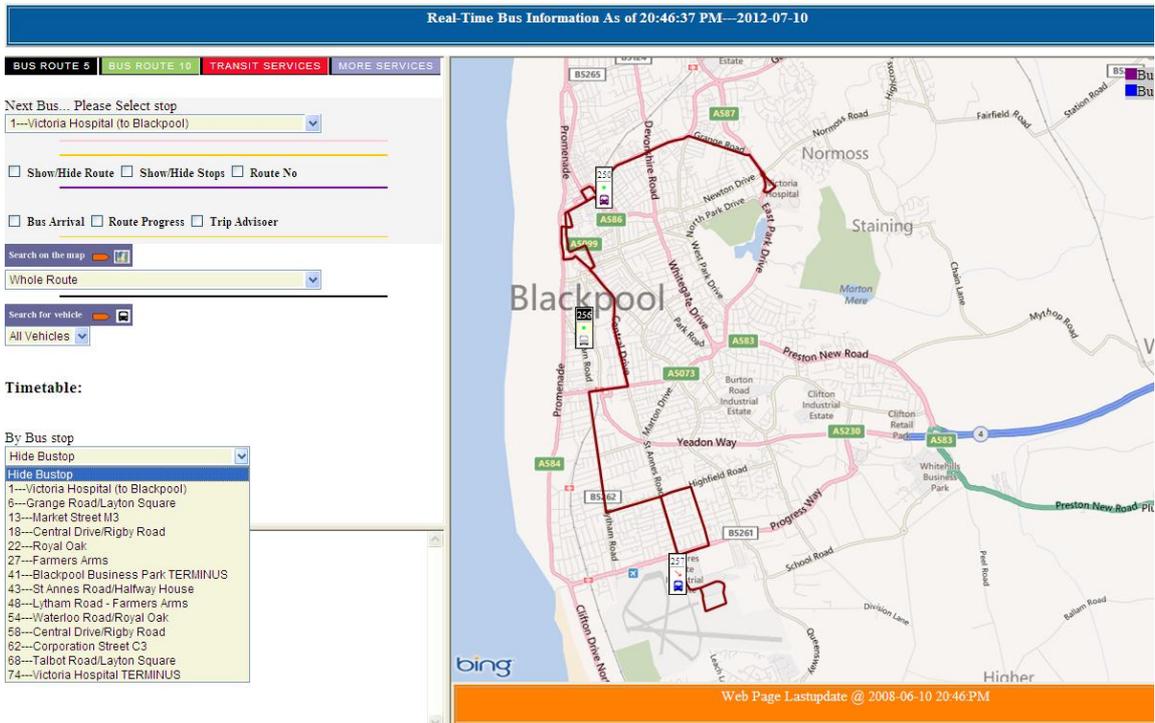


Figure 5-4 Public passenger interface to transport system shows a variety of transport services

As we can see in Figure (5-3) and (5-4), the user interface has been divided into parts and the user can navigate between them easily. The first tab menu in Figure 5-3 displays the bus data of bus route No. 5, while the second tab menu displays the bus data of a different bus route. This is to show the system's ability to manage and organize more than one bus route. As for the other two tabs in Figure 5-3, they offer the user a variety of tools to find information. Through the user interface, passengers can access real-time transit information, display and review information for a particular bus. Passengers can search by bus route to display the map of that route, and the stops along the route, as shown in Figure (5-5).

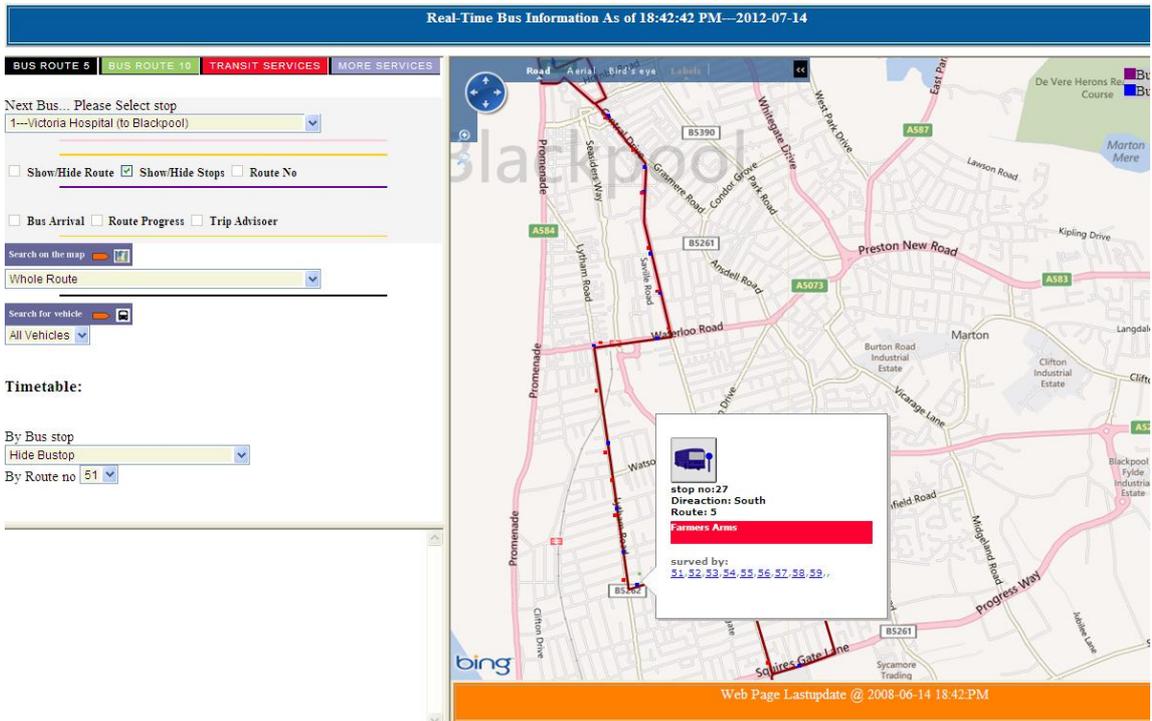


Figure 5-5 Transit stops along Blackpool Route 5

Our system provides a next bus service where passengers select a particular bus stop to enquire about upcoming vehicles. The system will also show transit vehicles and estimated times of arrival. As shown in Figure (5-6), a list of bus stops and next bus service is illustrated.

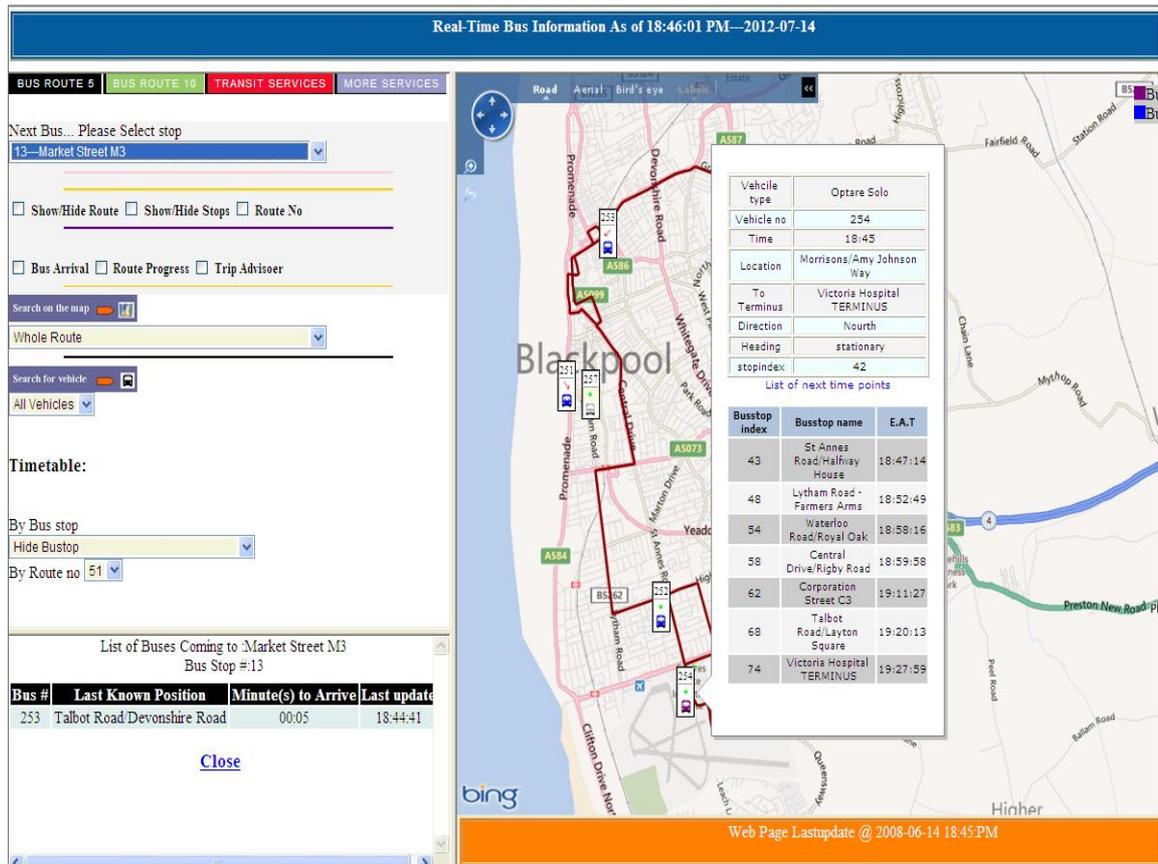


Figure 5-6 Upcoming transit vehicles to selected bus stop is shown

In addition, through the user interface, users can search for a particular bus stop or transit vehicle on the map, and subsequently the location of the bus stop or the current location of the vehicle is shown on the map with associated transit information. As we can see in Figure (5-7), transit vehicle no 252 is selected and its transit information is shown.

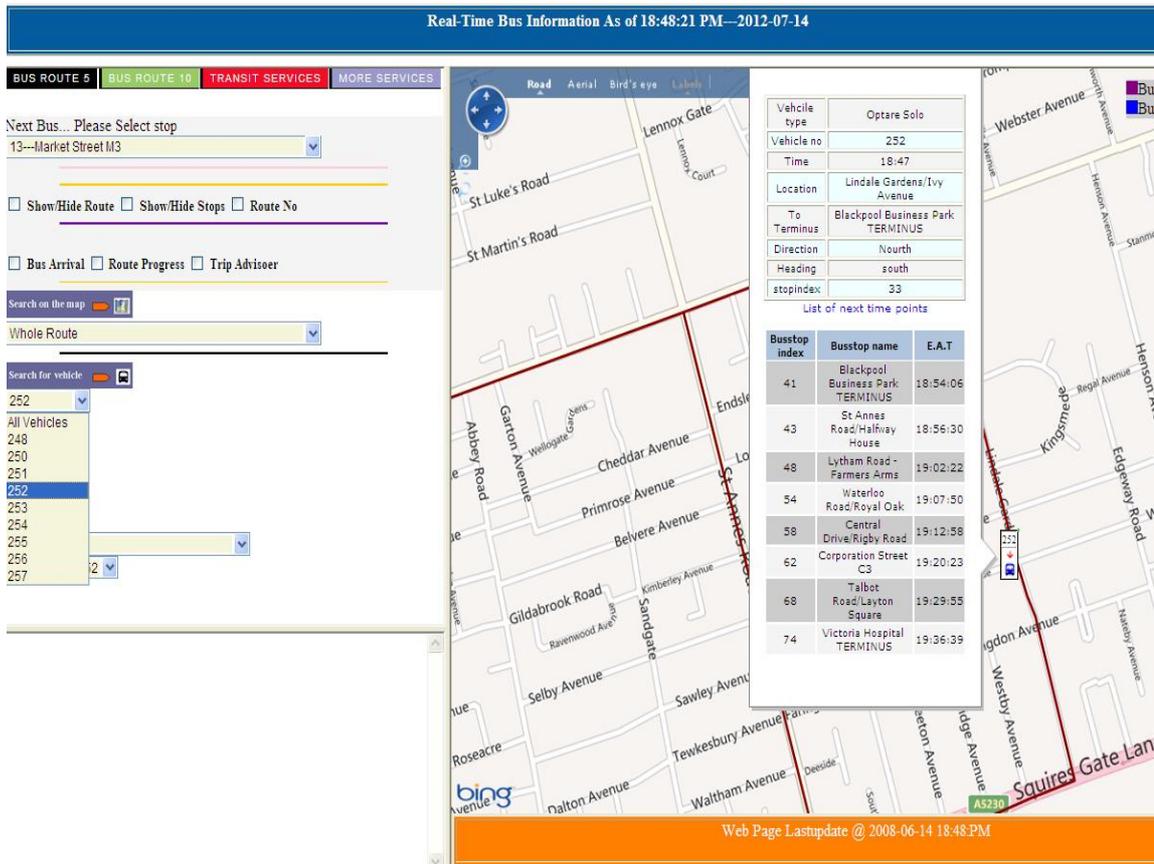


Figure 5-7 Transit vehicle detailed information

In a similar way, as shown in Figure (5-8), the location of a bus stop is shown on a map with a detailed information window indicating the upcoming bus and the expected arrival time.

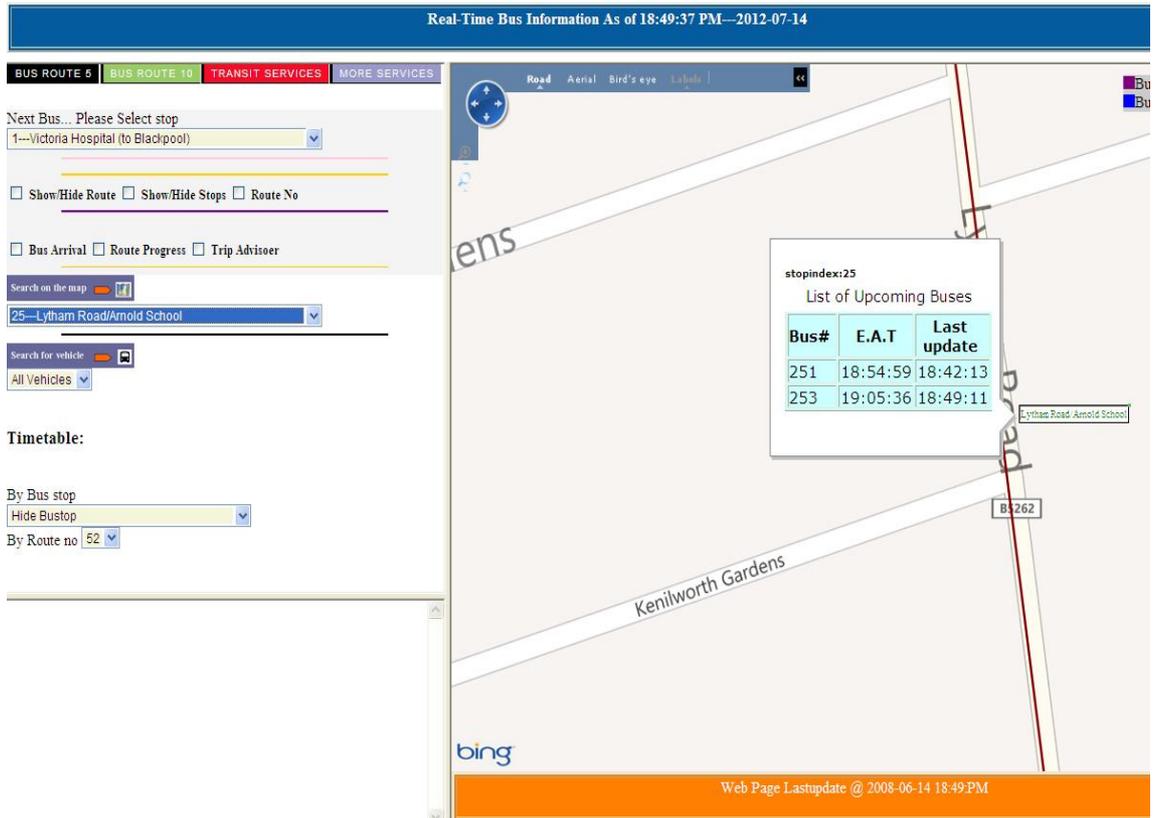


Figure 5-8 Web interface, showing a transit stop on Route 5, with detailed information

For more services, the transport system provides passengers with a service to search for a particular Point of Interest or landmark on the transit map and access information such as the nearby bus stops together with the associated transit information. Figure (5-9) shows the Blackpool tower and the nearby bus stops and associated transit information.

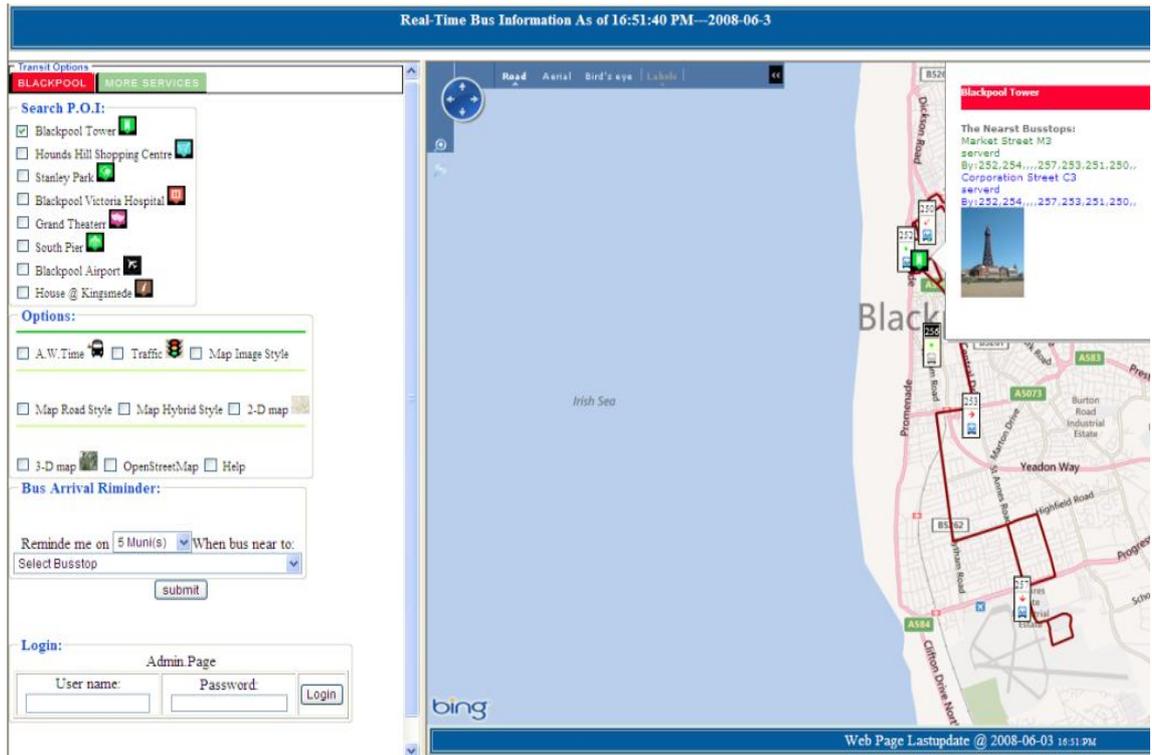


Figure 5-9 A point of interest and the associated transit information is shown on a map

Passengers can access timetable information using a particular bus route or bus stop. Figure (5-10) shows timetable information for bus stop no 41.

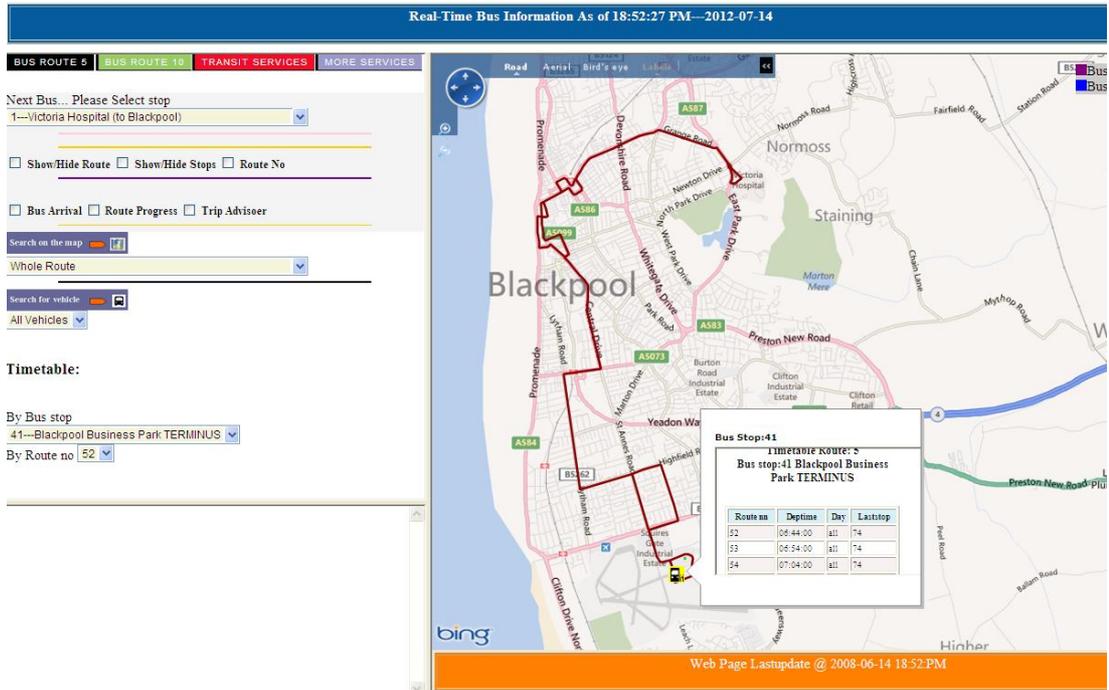


Figure 5-10 Access timetable information

For any bus route and real-time progress of the transit vehicles on the route, passengers can see the progress through an alternative graphical view that displays the current location of vehicles along a particular bus route. Figure (5-11) shows the bus progress along the bus route. Vehicles location and estimated arrival times are updated on this view as new data is obtained.



Figure 5-11 Route Progress View

To avoid lengthy waits at bus stops, passengers can set an alarm to notify them when a transit vehicle is within a predefined walkable distance. The alarm will automatically notify the passenger via a browser alert. For example, in Figure (5-12), the alarm notification is adjusted to five minutes before a transit vehicle arrival at the selected bus stop or station, (Market Street M13). When the bus is at a distance of 5 minutes the alarm alerts the passenger by showing a message on the screen. This can

help to save passengers time, so they can spend their time productively on other activities near the transit stop.

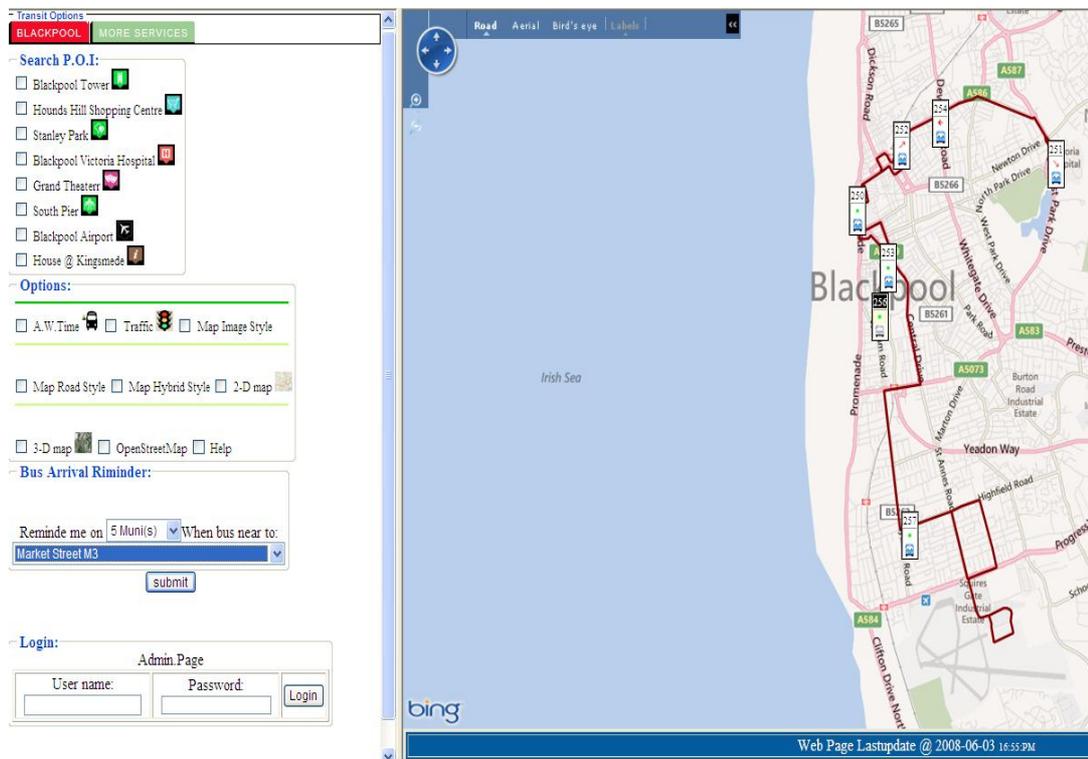


Figure 5-12 Setting an alarm notification by selecting the time and bus stop of interest

Additionally, the system utilizes schedules or/and actual vehicle location reports and provides air terminal styled arrival/departure status. Passengers can access vehicle arrival/departure times for all bus stops. This can help passengers to track particular transit vehicles while they are in service. Figure (5-13) shows the last known position of a bus and bus arrival times in minutes to the bus terminus, along with real-time location on the transit map. This service can be accessed through the “Bus arrival times” option on the user interface.

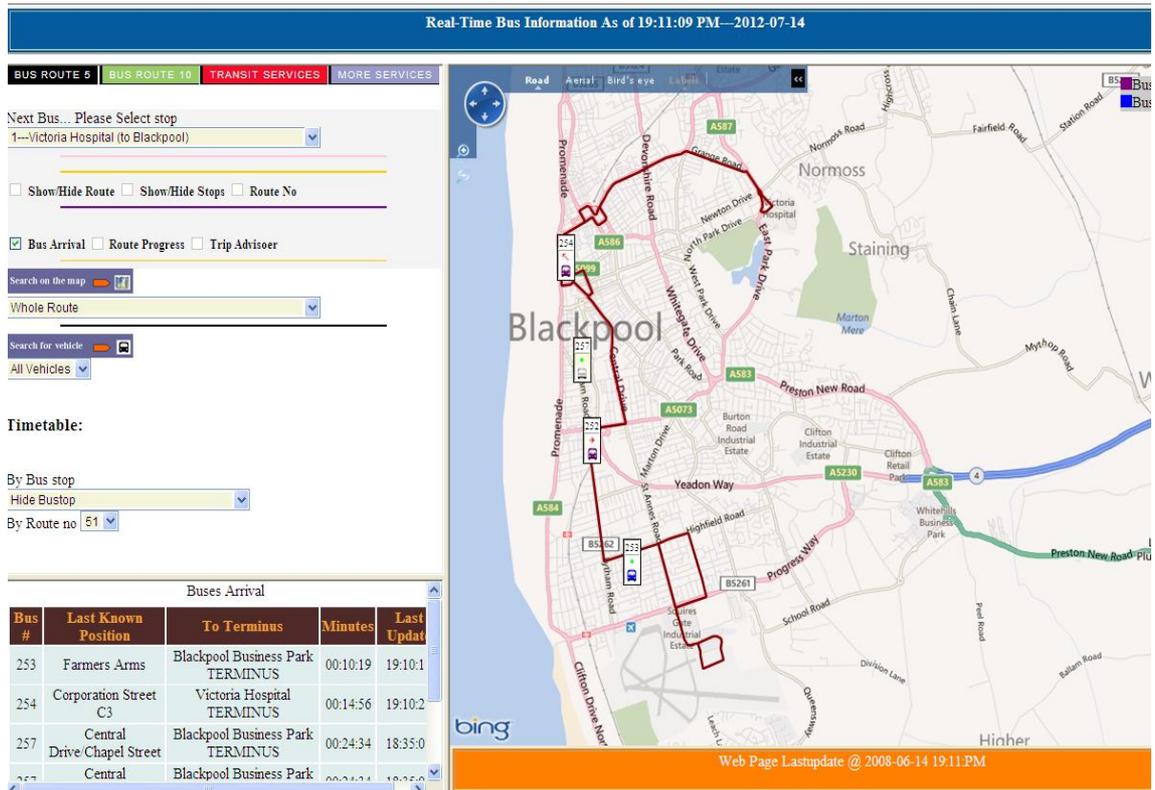


Figure 5-13 Bus arrival times in tabular format

A trip planner service is available for passengers to plan their trip in advance and obtain pre-trip information. This tool, as we will discuss in Chapter 6, integrates real-time transit information with pedestrian navigation systems to provide passengers with door-to-door journey planning information, utilizing real-time transit information instead of static timetables.

### 5.4 Interaction by Delivering Location Based Services (LBS)

According to (Virrantaus et al. (2001), Location Based Service (LBS) is an information service accessible with a mobile device through a mobile network and utilizing the ability to make use of the location of the mobile device. As we can see in Figure (5-14), LBS has four basic components: mobile devices, communication network, positioning component and service provider.

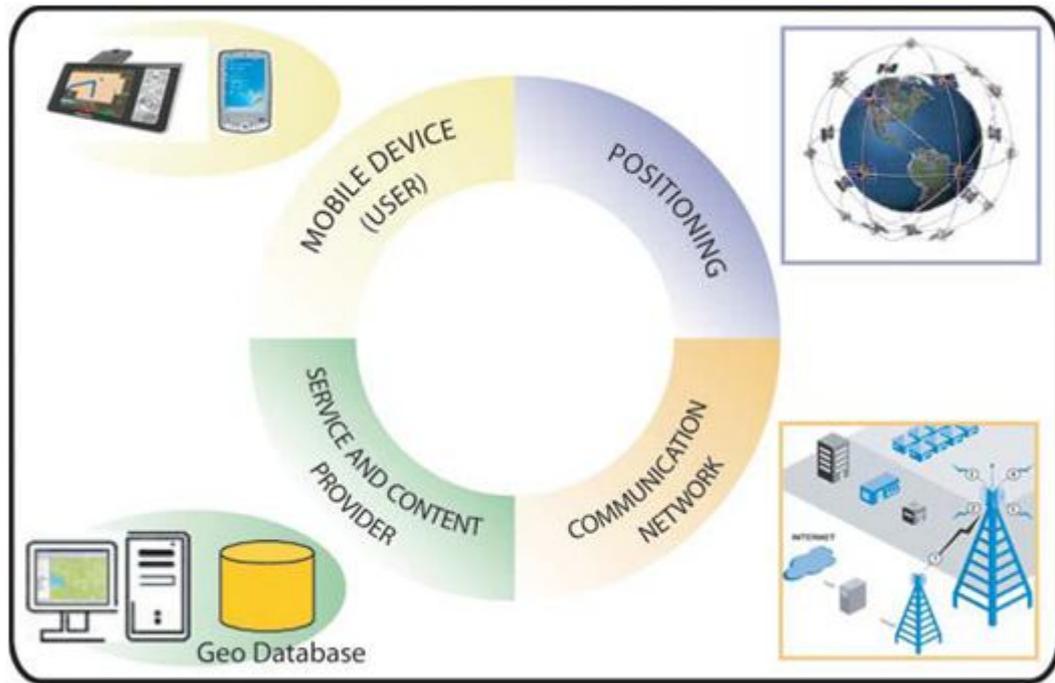


Figure 5-14 The basic components of LBS (Source: Shiode et al 2004)

LBS technology intersects three technologies. It is created from New Information and Communication Technologies (NICT) such as mobile telecommunication systems and hand-held devices, the Internet and Geographic Information Systems (GIS) with spatial databases (Shiode et al., 2004). Figure (5-15) illustrates the intersection of LBS technologies. The basic idea of location-based services is to answer the questions, “Where am I? What is around me? Where is it?” When individuals find themselves in an environment they are not familiar with, their needs and behaviour can be anticipated. People need to find somewhere to stay, to eat, to withdraw money from an ATM or directions to a particular place. Location based service technologies are integrated to deliver information to users based on their needs.

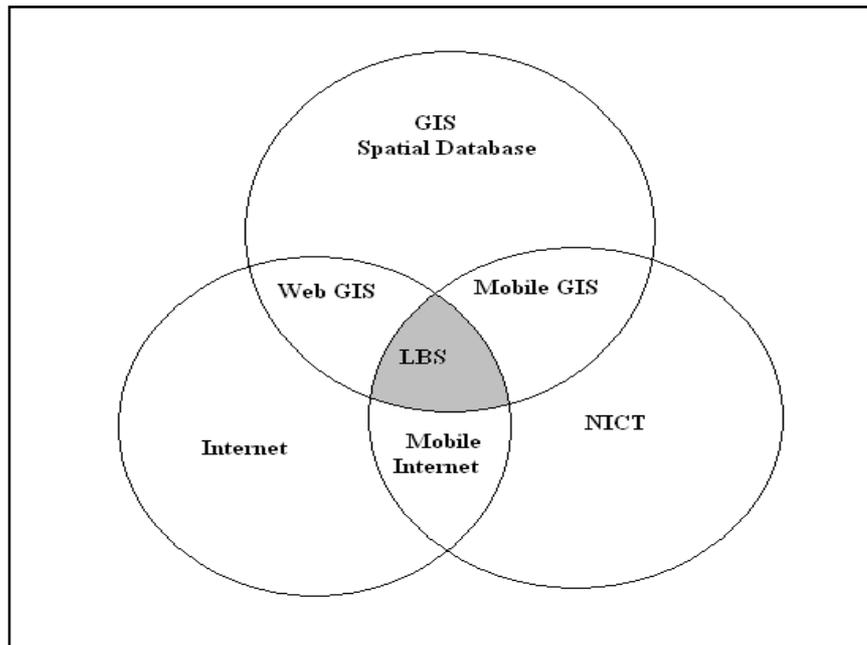


Figure 5-15 LBS as an intersection of Technologies (Source: Brimicombe, 2002)

#### *5.4.1 Mobile Devices*

Mobile devices are used to receive information or services. The content can be text, pictures or video. There are hundreds of types of mobile devices today, such as the mobile phone, personal digital assistants, pagers, personal navigation devices and many more. They are available with various applications and functionalities. A mobile phone may be the most suitable device to be used for LBS implementations due to its popularity and capability for supporting the requirements. Several mobile phones devices have emerged recently with the advent of advanced geo-technologies (TCRP, Synthesis 91, 2011).

#### *5.4.2 Communication Network*

The mobile network facilitates data transfer between mobile devices and the service provider. In location-based service applications, the communication network generally represents a wireless mobile network that serves two-way communications. It collects the data sent by the client, transfers it to the service provider and sends back to the client the particular result based on user information. The existing mobile

networks are classified into several categories based on purpose, range and transmission distance (Brimicombe, 2002).

#### *5.4.3 Positioning Technology*

The user's position should be determined first to be able to receive relevant services or information. Positioning technologies are used to identify the mobile phone's location using GPS or mobile network-based positioning (TCRP, Synthesis 91, 2011). GPS has high accuracy compared to mobile network positioning. Despite its accuracy, GPS has a weak satellite signal because its satellites are in high orbit and are broadcasting over a large area. This system is not suitable for indoor usage, within areas that do not have good signal strength or in areas where the signals can bounce off reflecting objects such as tall buildings. Mobile Network Based Positioning (Isaac. K. A., et al, 2002) is used for devices that do not have integrated GPS chips. The advantage of network-based positioning over satellite-based methods is the stronger signals and the availability for indoor use. However, although network-based positioning is quite cost-effective, the accuracy is often not ideal (etutorial, 2012).

#### *5.4.4 Service Provider*

In LBS, the service provider offers a variety of services to the user. Some of the common services that a service provider offers are data content, processing, storage, wireless network infrastructure and handsets. Content providers present data including business listings, topography, road information and some specific landmarks such as hospitals, hotels, restaurants, airports, railway stations, etc. In this research, a location-based service is considered to be a special subset of the area of "context aware services", as it can automatically adapt the user location to be matched with a database and deliver useful information to the user. Figure (5-16) shows the communication architecture of an LBS Service and Bus Tracking System. As we can see from Figure (5-16), passengers can utilise their location and establish communication with the service provider to obtain transit information such as the nearest stop, upcoming buses and estimated times of arrival.

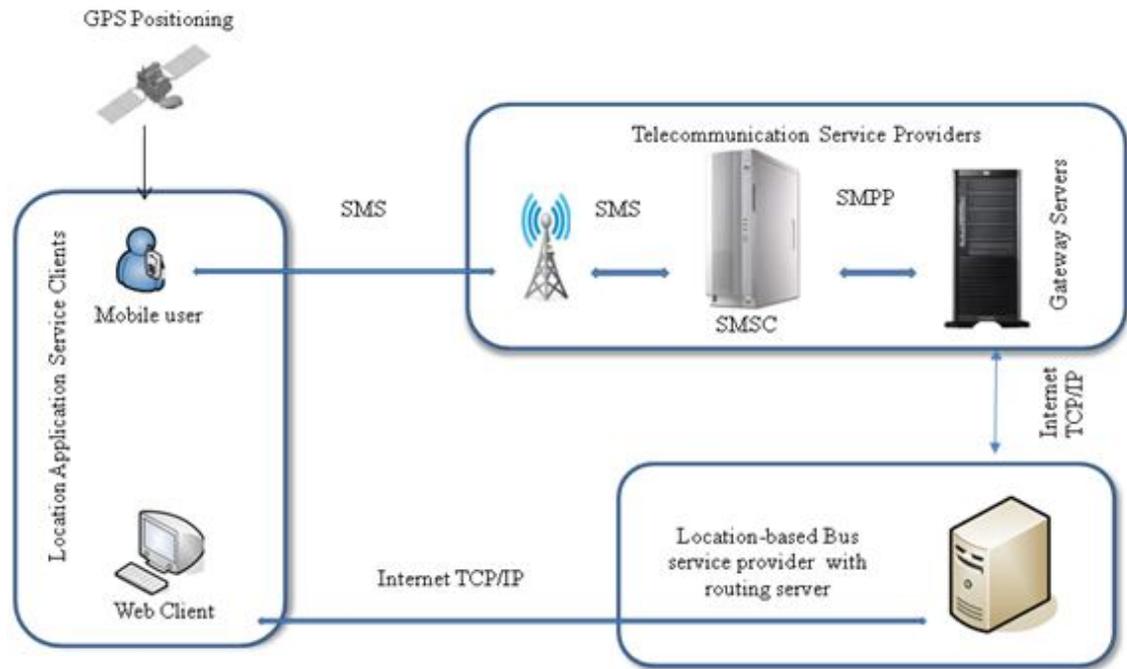


Figure 5-16 LBS Service and Bus Tracking System Communication Architecture

### ***5.5 Pedestrian Navigation System: A Specific Interaction***

Pedestrian navigation systems optimise the route for walking and provide detailed information about routes, they enable people to retrieve precise instructions to reach a specific location (Millonig, A. and Schechtner, K., 2007; Hile, H., et al, 2009). These systems utilize a GPS unit to determine user position, and provide directions based on user movements (Aiden M., et al, 2012) Pedestrian navigation systems calculate the amount of time it will take the user to reach his or her destination by measuring the distance to the destination. Navigation systems have the most important part of the mapping market. It accounts for over 70% of the \$2 billion mapping market (Techcrunch, 2012). Free mapping application program interfaces (API) like (Google Google Maps, 2012), (Nokia Map ,2012), (Bing Maps, 2012), (Yahoo Map, 2012) and (Navteq, 2012) have included pedestrian and routing navigation as the major part of their mapping services. They have popularised the use of online maps for pedestrians. Users can very easily download the application onto a smart mobile device and use it on the move. Pedestrian navigation applications can help pedestrians navigate through unfamiliar cities, for example, and guide them to various points of interest. Pedestrian and Routing services are

available to create customised map-based applications which combine cartographic data with the user's own data.

## ***5.6 Integrating Pedestrian Navigation with Real-Time Bus Data***

Journey planners, also known as trip planners, are specialized electronic search engines that find the best journey between two points by some means of transport (Journey planner, 2012). (Smith, 2000) explained that the goal of a trip planner is to minimise total trip time. A few applications like (Transportdirect, 2012) (travelinemidlands, 2012) and (Google Transit 2012) provide the user with these functionalities. These applications give users the arrival time of the bus based on the timetable that the bus operator provides, which, however is subject to deviation due to traffic congestion or other operational factors. Many transit agencies now offer online trip planners for their systems (Radin et al, 2002). The transit trip planner applications prompt users to input origins and destinations to generate routes between points using available transit services.

Utilizing LBS, our public transport software system provides passengers with routing services as well as real-time transit information. Our trip planner sub-system finds the nearby transit stops within walking distance of a desired origin or destination. The system links the origin or destination to real-time transit information as well as determining the total trip time (Shalaik et al 2010b). It uses Bing Maps, which provides an API for routing and geo-coding services. The user enters a geo-coded origin and destination and the sub-system must respond by returning the shortest path to the nearest stop based on the real-time state of the transport network. The integrated system works between the transit server and the routing provider. Figure (5-17) shows the steps of the trip planner system using Real-Time Bus.

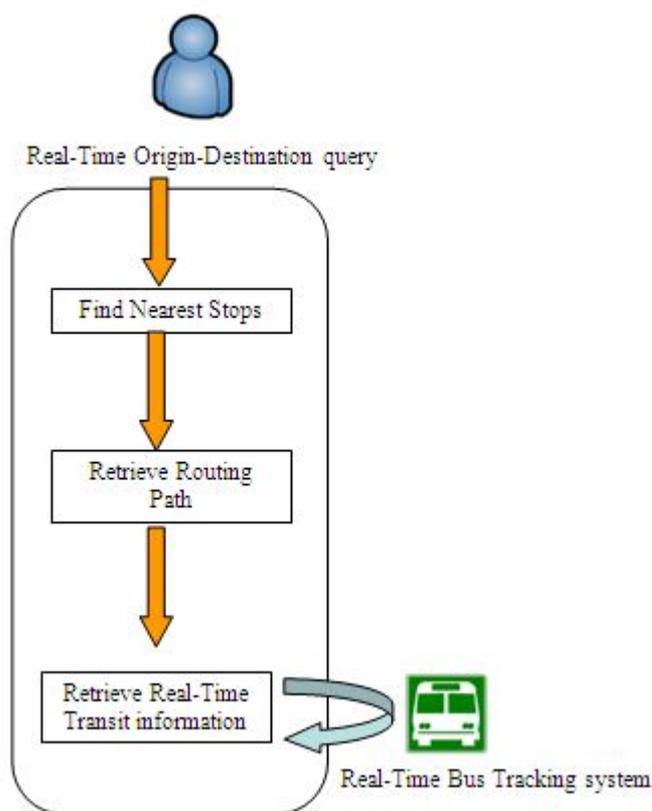


Figure 5-17 Workflow of algorithm of Journey Planning System using Real-Time Bus

The trip planner system provides transit users with an interactive, easy-to-use trip planning application. This system can be a text-based or a map-based system. The system interface serves two different purposes such as collecting information from the users as input and providing information back to the users. All the data and the core computing are done on a server. Figure (5-18) illustrates the web-based interaction of the integrated trip planning sub-system. Start and destination points are sent to the Bing maps API through the transit server, the response (Route description) is sent back in XML format where it is parsed and shown to passengers.

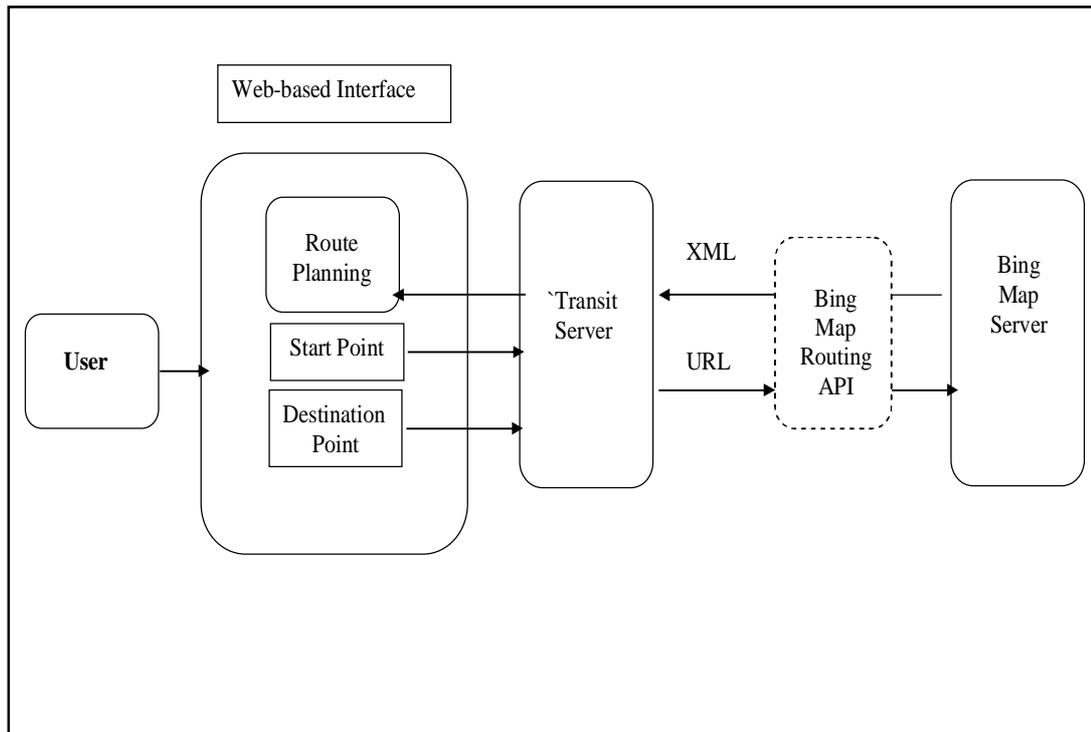


Figure 5-18 Web-based interaction for Journey Planning System

### 5.6.1 Web-based User Interface

As seen from Figure 5-18, the web-based interface enables transit users to select the start point/current location and destination point. Three variables are taken as inputs, namely the start point, destination and timestamp. Based on the user's destination, the trip planner system will determine the direction of the journey, taking into account the starting point and the stops surrounding the required destination. Once the journey direction is determined, the trip planner system determines the closest stop that can be used by the passenger to reach the final destination.

The routing algorithm of the trip planning system is provided by the Bing Map Routing API. This algorithm provides routing directions including the time required to walk through the shortest path to the nearest bus stop and, after checking for the next available buses towards the destination, suggests when the user should start walking to the nearest bus stop. Figure (5-19) illustrates the system flowchart of the Journey Planning System.

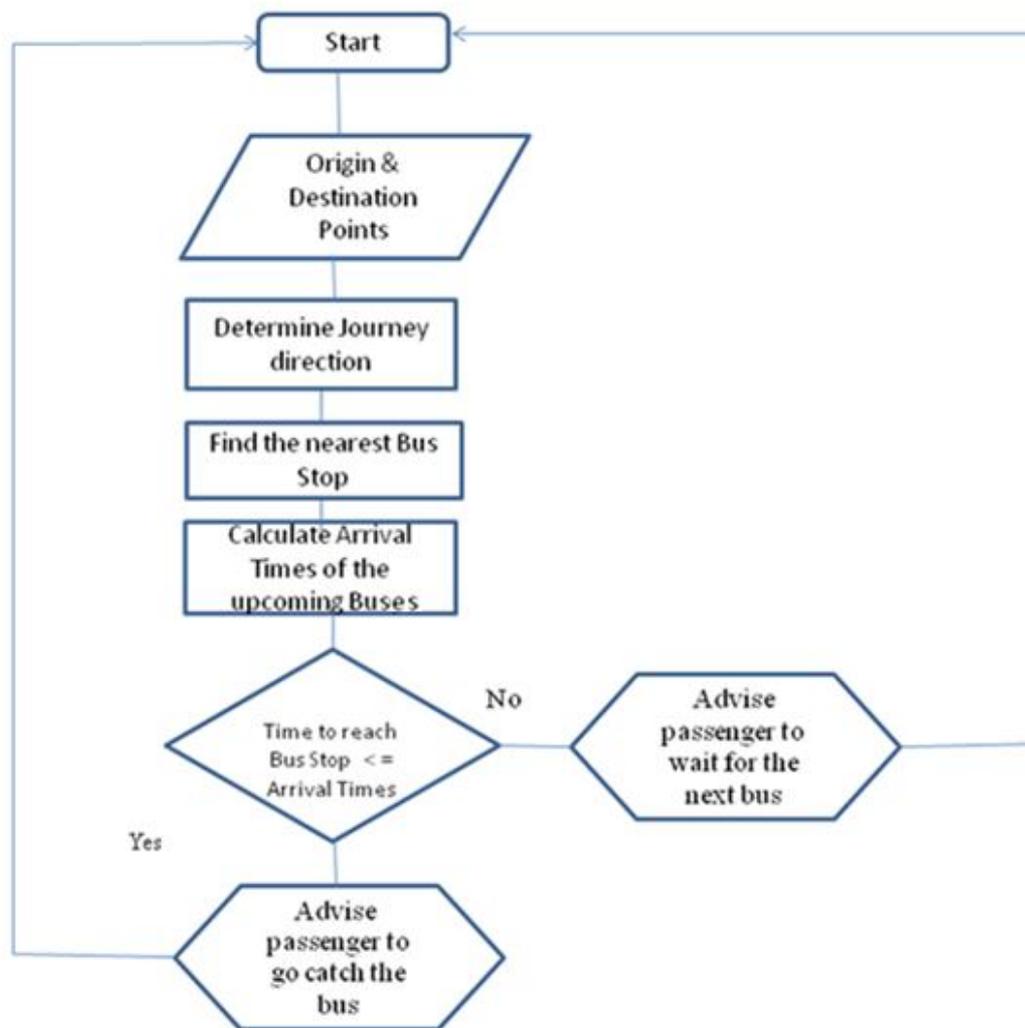


Figure 5-19 System flowchart of Journey Planning System

The main functionality of the integrated system is to reduce the total trip time, including waiting time at the bus stop for the next bus, and provide passengers with directional information. Figure (5-20) shows the public interface for the integrated real-time bus tracking and pedestrian navigation system. The routing functionality is applied using the Bing Map REST services Application Programming Interface (API) (Bing Map, 2012), which provides a Representational State Transfer (REST) interface to perform tasks such as creating a map with pushpins, geocoding an address, retrieving imagery data and creating the route.

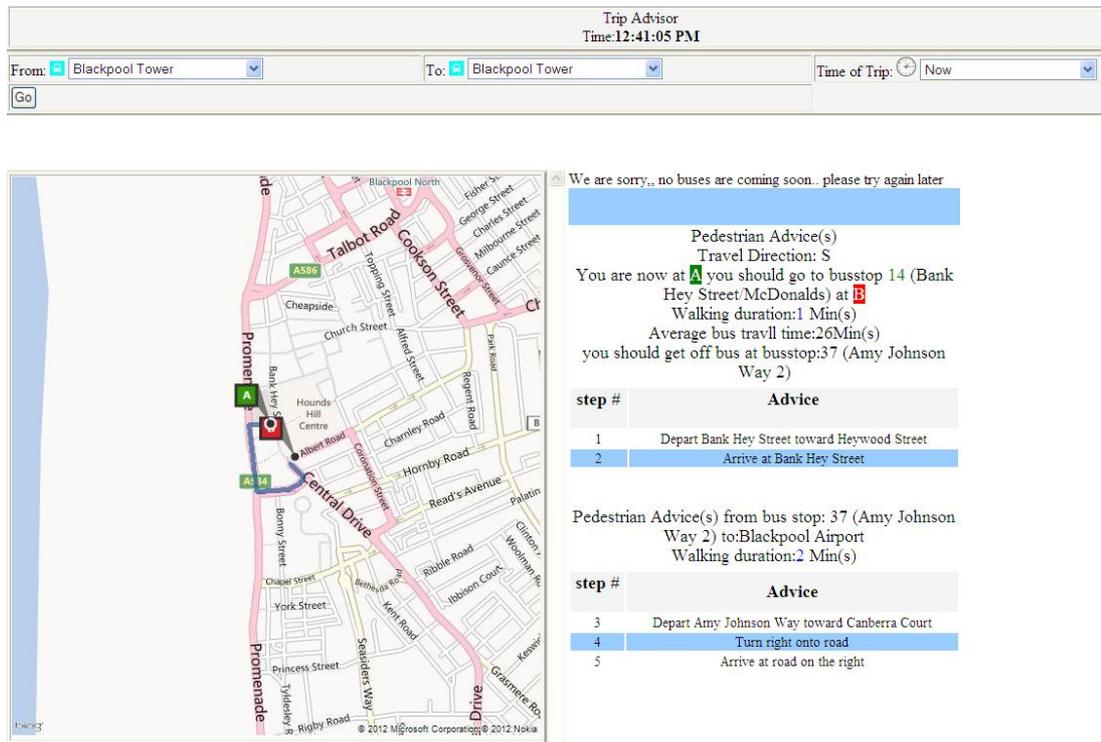


Figure 5-20 Public interface for an integrated real-time bus tracking system with pedestrian navigation

### 5.6.2 Bing Map Routing API

The Bing Maps Routes API can be used to create routes that include two or more locations and to create routes from major roads (Bing Map, 2012). Users have the option of creating routes for both driving and walking. Driving routes can include traffic information and the final routes can be overlaid on map imagery. The API uses the REST and SOAP protocols and responses are formatted in XML (XML, 2012), JSON (JSON, 2012) and JSONP (Microsoft, 2012).

Bing Maps Routes API uses the URL to get a walking, driving or transit route by specifying a series of waypoints. A waypoint is a specified geographical location defined by longitude and latitude that is used for navigational purposes. The route includes information such as route instructions, travel duration, travel distance or transit information. It is also possible to request a set of route points. In our system we used PHP toolset to convert XML to an object that can be processed with normal

property selectors and array iterates. For example, we used SimpleXML element extension to convert XML format.

In order to display a static map route, a URL in the following format must be sent: `http://dev.virtualearth.net/REST/v1/Imagery/Map/Road/Routes&wp.0=a,b&wp.1=c,d&key=bingmapkey`. `wp.0` is the current coordinate, `wp.1` is the destination coordinate and `Bingmapkey` is the API map registered on the Bing service.

### *5.6.3 Developing Models for Routing*

To construct routing procedures we can use either of these typical software development strategies:

- Third party APIs
- Implementing original routing algorithms

The first is convenient and fast for the developer to deploy applications. However, if there are special requirements, for example if people have preferences such as passing through buildings as much as possible because it is raining heavily, it becomes necessary to develop more parameterized routing modules.

### *5.6.4 Mobile-based Interface*

A text-based mobile interface was designed to show textual routing information.

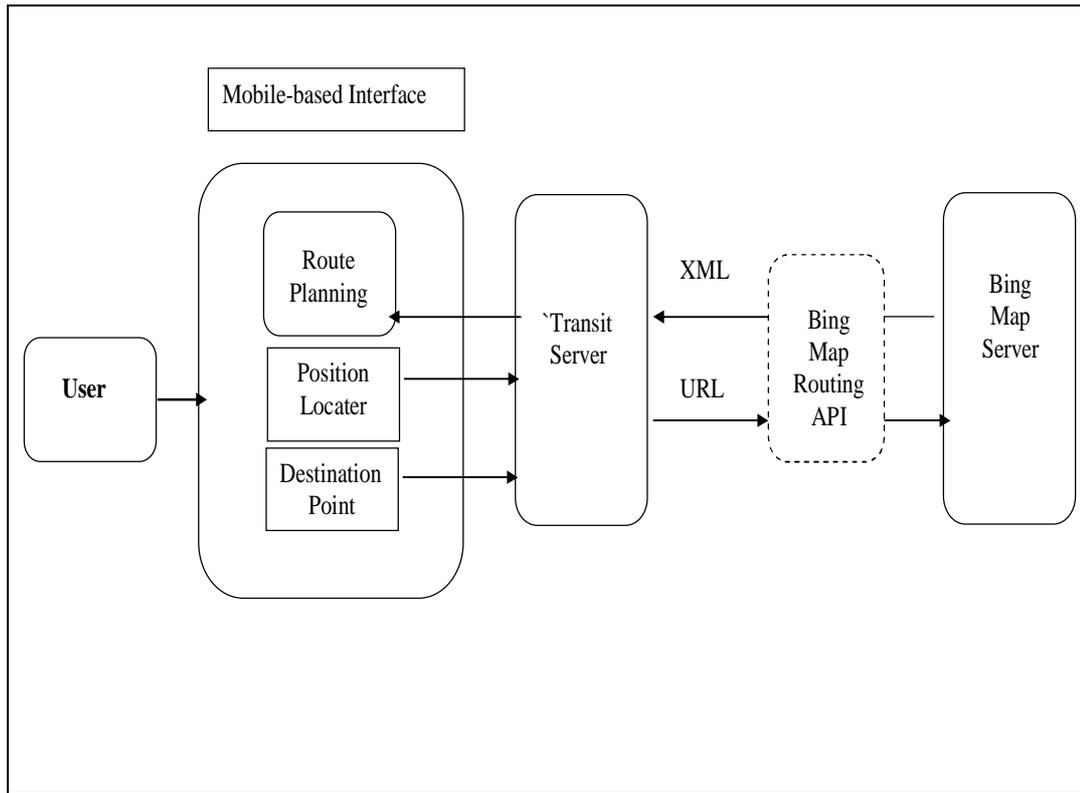


Figure 5-21 mobile-based interaction integrated system

As we can see from Figure 5-21, the user destination along with the passengers current location and timestamp, will be sent to the transit server. These parameters are sent to the server through the mobile network. The system will determine the nearest bus stop and consult the routing provider (Bing Maps Routes API) for routing directions and the walking time needed to reach the bus stop. The transit server provides the arrival times of the potential upcoming buses towards the nearest bus stop, connects to the remote server and sends the request parameters. When the results are received by the mobile device, it will make them readable and display them on its screen. The real-time information helps users to organize their trips based on the actual arrival times of buses and reduces their waiting time at bus stops.

### ***5.7 Smart-Mobile-Based Interaction Scheme***

Mobile phones are ubiquitous; they are one of the few devices that have computation, various sensors and communication capabilities. Our public transport

software system is accessible through a variety of interfaces. It can be accessed through a dedicated website, as well as through an application for mobile devices. The mobile application is of particular interest because of the potential to integrate location sensing technologies such as GPS with real-time transit information systems. The location and timestamp information of both passengers and transit vehicles can make filtering easier, so that the relevant information can be found more quickly. The use of combined features of mobile phones such as vibration feedback may improve the interaction between passengers and public transport systems. Passenger information is often a critical element of a public transport system's objectives, not only for providing transportation services but also for encouraging and facilitating the use of these services. Real-time information for buses, subways, light rail, and other transit vehicles are displayed in a significant number of cities worldwide at places such as rail stations, transit centres and major bus stops. With the possibility that real-time transit information will not be available on a public display at every stop, mobile phones can help to manage the complexity of using transit information. Mobile phones can also provide schedules, routes and real-time arrival information.

Instead of publishing static information on the Internet, the development of dynamic transit system applications (which can be tailored to mobile devices) is rapidly broadening the scope of public transportation information provision. Public transit systems can inform passengers of the precise location of the transit vehicle they wish to catch or estimate the arrival times of the next vehicle at a particular bus stop and deliver this data to a mobile device in different formats such as textual, colour-coding or vibration alarms.

Today, most smart phones are equipped with built-in Global Positioning System (GPS) receivers, digital compasses and accelerometer sensors, which allow for location aware applications. The availability of these devices has created a challenging environment in terms of developing real-time transit applications for mobile devices. These applications bring considerable potential for improvement in the way that people use public transport systems and access information about the services. Shwu-Jing et al (2005) designed and implemented a location aware mobile transportation information services with a map database for a public bus network.

The system provides map-based information on the nearest “Mass Rapid Transit” (MRT) station, the nearest bus stop on the bus route chosen by the user, and the nearest bus stop on the route that can take the passengers to their chosen destination. In (Maclean, S.D., Dailey, D.J., 2001), WAP-enabled cell phones were considered as a suitable device for receiving real-time transit information.

### *5.7.1 Bus Arrival times on a Smart-Mobile Device*

To help transit users receive bus arrival/departure times on their mobile devices, the process for delivering information on the Google Android platform (Google Developer, 2012) and mobile interfaces were designed using the Android operating system and the Java programming language (Shalaik, B. et al., 2011b). Android also provides C/C++ libraries, such as SQLite, for the development of various systems (Sunguk, L. 2012). The physical restriction of the mobile device was overcome by using an appropriate user interface design. The system provides real-time information about bus routes and bus locations for those who have a mobile device with internet accessibility. They can link to the transit server and get current transit information such as bus arrival time to the nearest bus stop.

The application framework is a layer to provide system flexibility and reusability. A “HTC” Magic smart phone that runs on the Android operating system was used to communicate with the transit server. The mobile device uses a HTTP protocol to connect with the database on the server. Figure (5-22) illustrates a sequence diagram of the interaction between passengers, mobile devices and the transit server web. To view arrival/departure time on the mobile device, the passenger selects the preferred destination. The transit system then collects the passenger’s current location from the built-in GPS. The user’s current location along with the chosen destination are sent to the server using the HTTP protocol by appending it to the URL that connects to the server. The URL from the mobile device is then transmitted and the response is displayed on the mobile screen. The nearest bus stop to the user’s current location is suggested and the bus arrival time is displayed on the device.

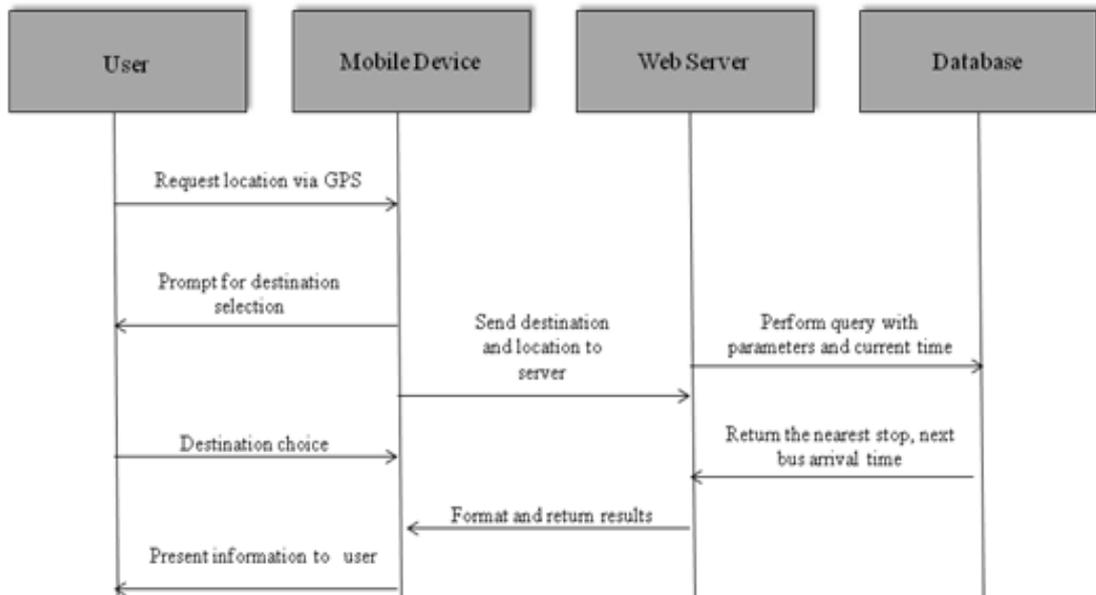


Figure 5-22 A sequence diagram shows the interaction between passengers, mobile devices and the web.

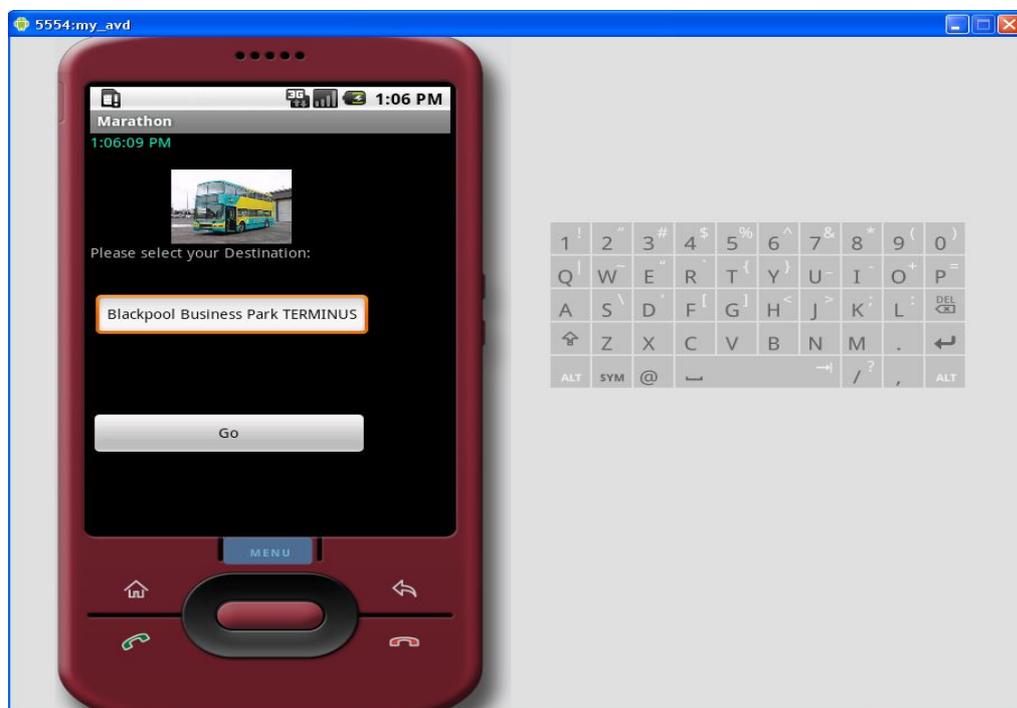


Figure 5-23 Mobile interface on an Android emulator where the transit user selects the destination bus stop

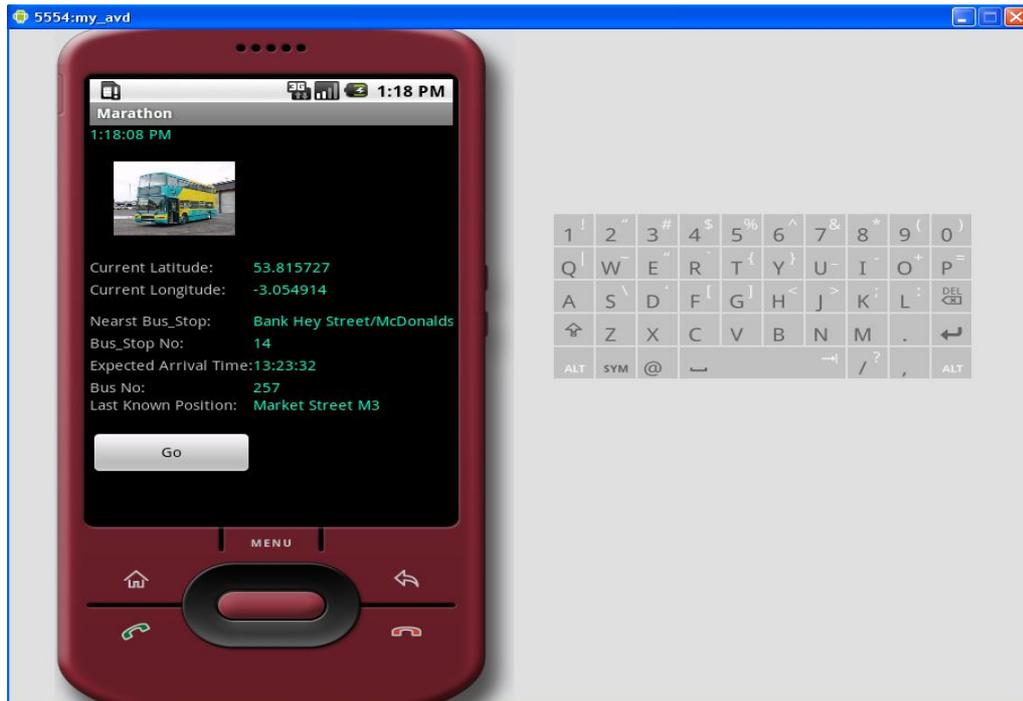


Figure 5-24 Mobile interface on an Android emulator where the transit user receives real-time transit information

As seen in Figures (5-23) and (5-24) mobile interfaces are shown on an Android emulator. In Figure (5-23), the user selects the destination and clicks a button, the system then identifies the nearest bus stop the user can go to, to reach the destination. Information such as the upcoming bus(s) and the estimated times of arrival is also shown in Figure (5-24).

### ***5.8 Enhancing the Mobile Interface: Including Haptic Feedback***

Haptic technology or (haptics) is a tactile feedback that takes advantage of our sense of touch by applying forces, vibration and/or motion to the user through a device. The term “haptics” arises from the Greek root “haptikos”, meaning “able to grasp or perceive” (Ralph H., 2004). (Heikkinen et al, 2009) state that our human “sense of touch is highly spatial and, by its nature, tactile sense depends on the physical contact to an object or its surroundings”. With the emergence of smart phones that come enabled with various sensors like an accelerometer, gyroscope, compass and GPS, it is possible to develop applications that provide navigation information in the form of haptic feedback (Pielot et al., 2010). From computer games to virtual reality

environments, haptics have been used for a long time (Van Erp, J, 2001). One of the most popular uses is the Nintendo Wii controller, which gives the user force feedback while playing games. Some touch screen mobile phones have integrated force feedback to represent key clicks on screen using vibration produced by the phone. (Joseph L., et al 2006) described the design effort to match the potentials of haptic technology to the challenges of contemporary mobile interaction design. The aim was to explore how tactile technology can meet user needs in ways that are not currently met by visual and auditory interfaces alone.

Research into the use of the sense of touch to transfer information has been going on for some time. (Van Erp, J, 2001) who has been working with haptics for over a decade, discusses the use of the tactile sense to supplement visual information in relation to navigating and orientating in a virtual environment. (Kuber et al, 2007) proposed a structured participatory-based approach for developing targeted haptic sensations for the purpose of web page exploration. The study, which aimed to help blind people to access the Internet, reported preliminary results showing how HTML elements can be represented through the use of force-feedback. Findings were then compared with mappings from previous studies, demonstrating the utility of providing tailored haptic sensations for blind Internet passengers.

As haptic technologies develop and low-cost devices become more widely available, designers are beginning to realize the advantages of using the sense of touch to create accessible browsing interfaces. (Hoggan. E et al.,2007) feel that the integration of various sensors on a smart phone makes it easier to develop simple but effective communication techniques on a portable device. (Jacob et al., 2010) provide a summary of various uses of haptics and how it is being integrated into GIS.

HaptiMap (HaptiMap, 2012) is a project which aim at making maps and location based services more accessible by using several senses like touch, hearing and vision. The project's end goal is to increase the number of persons who are able to use mainstream map services. However, the design of LBS applications on mobile devices requires knowledge and understanding of several challenges such as (the user, the context, the technology, etc.) Where it requires knowledge of user's requirements, varying in the context and the limitation in the used technology.

In this research, we investigate the use of many applications that we propose to increase the level of communication between passengers with smart mobile phones and public transport systems. These applications use the haptic feedback as a means of delivering transit information to the user.

### *5.8.1 Vibration-Based Alarm for Passengers Using Public Transport*

In this section, we discuss the use of haptics in public transport systems, where we describe a mobile-based system that helps the user know his/her stop is nearing. The “PocketNavigator” application (PocketNavigator, 2012), which makes use of the GPS and compass, helps the user navigate by providing different patterns of vibration feedback to represent various directions in motion. The “PocketNavigator” application is described as a system that integrates OpenStreetMap data, Cloudmade Routing API (Cloudmade, 2011) and pedestrian navigation to provide navigation cues using haptic feedback by making use of the vibration alarm in the phone. Pedestrian navigation using bearing-based haptic feedback is used to guide passengers in the general direction of their destination via vibrations (Robinson, S. et al., 2010).

The main objective of our system is to overcome the ‘neck down’ approach of any visual interface which requires the user to look into the mobile screen for alerts. Thus we examine the integration of haptics into public transport systems. This system provides information about time and distance to the destination bus stop and uses haptic feedback in the form of the vibration alarm present in the phone to alert the user when the desired stop is being approached. The key outcome of this system is that haptics are being effectively used to provide feedback for public transport users.

While using public transport, the visually impaired or blind users found the most frustrating things to be ‘poor clarity of stop announcements, exiting transit at wrong places, not finding a bus stop’ among others (Marston et al, 1997). (Barbeau et al, 2010) describe a Travel Assistance Device (TAD) which aids transit riders with

special needs in using public transportation. The three features of the TAD system are:

- a) The delivery of real time auditory prompts to the transit rider via the cell phone informing them when they should request a stop;
- b) The delivery of an alert to the rider, caretaker and travel trainer when the rider deviates from the expected route;
- c) A web page that allows travel trainers and caretakers to create new itineraries for transit riders, as well as monitor real-time rider location;

Our system is similar to (Barbeau et al, 2010) which can be used by any passenger using public transport. Instead of depending on visual or audio feedback which will require the user's attention, we use haptic feedback in the form of a vibration alarm with different patterns and frequencies to give different kinds of location based information to the user. With the vibration alarm being the main source of feedback in our system, it also takes into consideration specific cases like "the passenger falling asleep on the bus" (Carmien et al, 2005) and also users missing their stop due to inattentiveness or visual impairment (Marston et al, 1997). The user selects the destination bus stop just before boarding the bus. The user's current location and the selected destination bus stop are sent to the server using the HTTP protocol. The PHP (PHP, 2012) script receiving this information stores the user's location along with the time stamp into the user's trip log table. The user's current location and the destination bus stop are used to compute the expected arrival time at the destination bus stop. Based on the user's current location, the next bus stop in the user's travel is also extracted from the database. These results are sent back from the server to the mobile device.

### *5.8.2 Integrating other Modes of Feedback*

Feedback to the user is provided using three different modes – Textual display, colour coded buttons, and haptic feedback using vibration alarm. The textual display mode provides the user with three kinds of information – 1) Next bus stop in the trip, 2) Distance to the destination bus stop, 3) Expected arrival time at the destination

bus stop. The colour coded buttons are used to represent the user's location with respect to the final destination. Amber is used to inform the user that he has crossed the last stop before the destination stop where he needs to alight. The green colour is used to inform the user that he is within 30 metres of the destination stop. This is also accompanied by the haptic feedback using high frequency vibration alert with a unique pattern, different from how it is when receiving phone call/text message. A red colour is used to represent any other location in the user's trip.

The trip log table is used to map the user's location on a Bing map interface as shown in Figure (5-25). This interface can be used (if he/she wishes to share) by the user's family and friends to view the live location of the user during the travel.

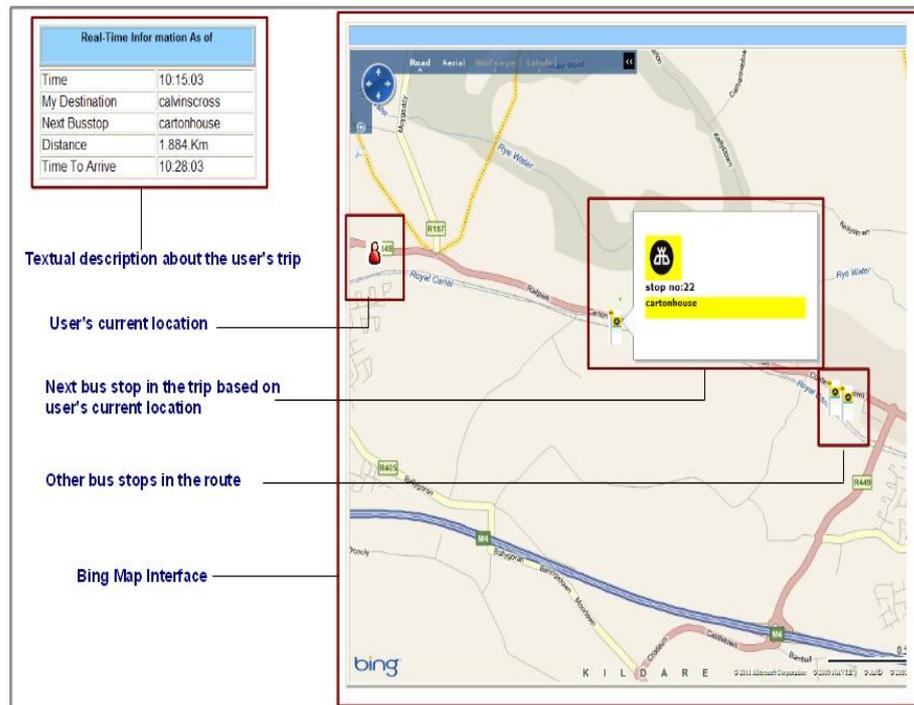


Figure 5-25 Displaying passengers location on a map

The textual and colour coded feedback requires the user's attention. The user needs to have the screen of the application open to ensure he/she sees the information that has been provided. Thus the user will miss this information if he/she is involved in any other activity like listening to music, sending a text, or browsing through other applications in the phone, like a game. If the user is traveling with friends, it is very unlikely the user will have his attention on the phone (Moussaid, et al, 2010). Thus

haptic feedback is the preferred mode for providing feedback to the user regarding arrival at a destination stop. Haptic feedback ensures that the feedback is not distracting or embarrassing like a voice feedback and it lets the user engage in other activities on the bus. Haptic feedback can be used by people of all age groups, and by people with or without visual impairment.

### *5.8.3 Integrating ‘point-to-query’ With a Real-Time Transit Information System*

The concept of using digital data obtained from location aware devices to interconnect with the physical world has been widely investigated and studied in the ubiquitous computing community. Many projects, such as the work of (Espinoza, F. et al, 2001; Lane, G. et al., 2003; Reid, J. 2004; Zhang L., and Paul C., 2009; Carswell, J., Gardiner, K., Jin, J, 2010; James D. Carswell and Junjun Yin 2012) are based on the common idea of attaching digital information to real-world places like a virtual post-it note or graffiti. By using positioning technologies like GPS or by deriving locations from the known positions of nearby radio (e.g. GSM or WLAN) or infrared sources, passengers can discover and access location-based information, participate in collaborative mapping activities, or engage in location-based social interactions (Melinger, D , 2004). Other location-aware applications are focused on orientation, (Wasinger, R, 2003) presented a PDA application which uses GPS and a digital compass to realize two-dimensional pointing functionality.

Various applications exist where the orientation of the mobile device is used to provide information to the user. “GeoWand”, one of the “spatial applications” of the future, was discussed by (Egenhofer M. J. 1999). The author defines “GeoWand” as an intelligent geographic pointer that allows users to identify remote geographic objects by pointing to them. “GeoWand” allow users to query features that are within the field of view by pointing their mobile device at the feature. Egenhofer M. J. (1999) developed an application based on innovative sensor-driven interaction metaphors, including Smart Compasses that point passenger users in the direction of points of interest and Smart Horizons that allow users to look beyond their real-world field of view and the aforementioned “GeoWands”. (Bantre et al., 2004) described an application called “UbiBus”, which is used to help blind or visually

impaired people to use public transport. The system allows the user to request in advance the bus of choice to stop and to be alerted when the right bus has arrived.

In our system for public transport services, we investigated the usage of smart phones in exploring transit information by integrating real-time bus data with a Location Based Services (LBS) “point-to-query” system (Shalaik, B et al, 2011d). This smart phone-based application enables passengers to retrieve real-time transit information using the orientation of the user point-to-query system, which provides the user with a textual description of query results about the availability of information required along a particular path or street. With this system, the users can point and query the availability of bus stops that are not directly visible to them but are along the path they intend to take. The system allows the users to use location, direction and orientation information to perform directional queries in the real world using mobile devices. The input to the system is through a visual interface where the user selects the destination he/she wants to go to as well as maximum distance wishes to walk in any direction. Figure (5-26) shows the steps involved in point-to-query system.

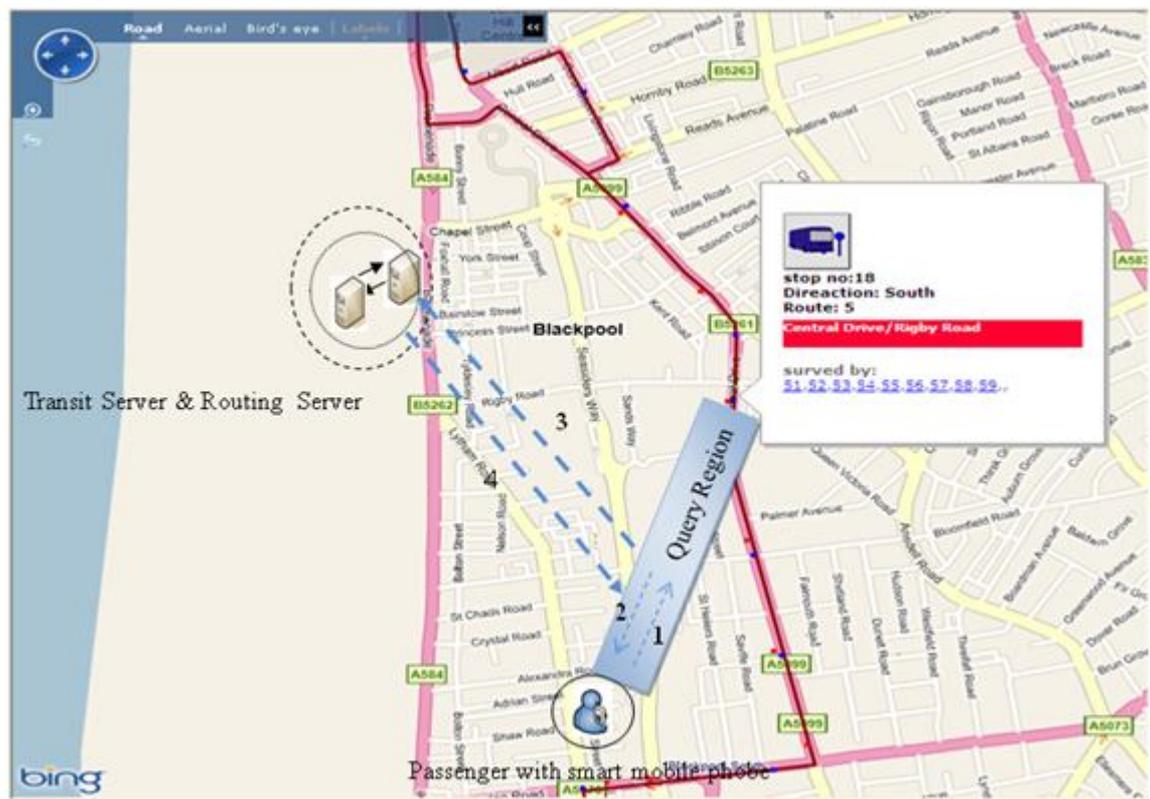


Figure 5-26 Using a smart mobile to explore transit information

The query region is created where the user holds the mobile phone parallel to the ground and “scans” the area. Scanning is performed by moving the phone parallel to the ground along the path from the user’s current location as illustrated in Figure (5-27).

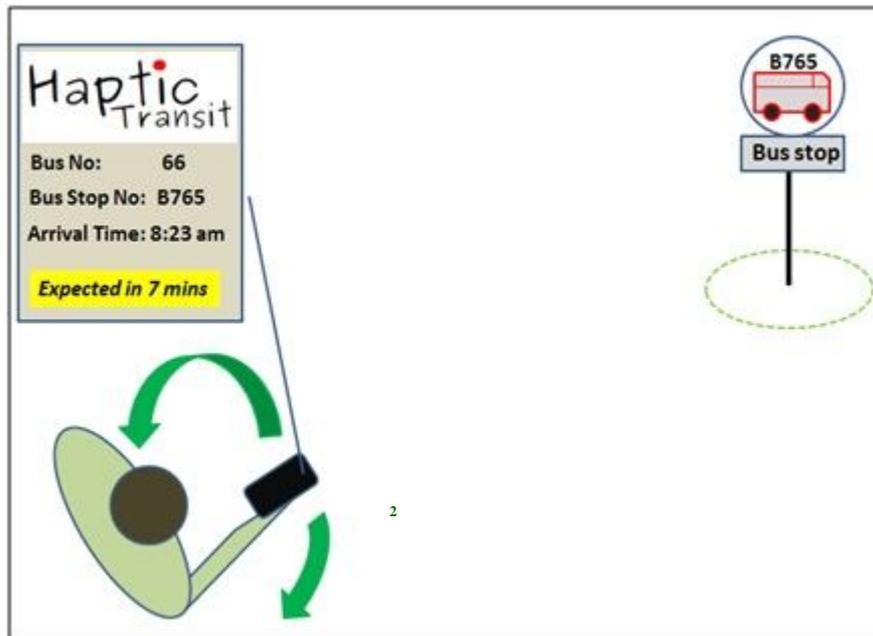


Figure 5-27 A Transit user scanning the area to find the location of the origin bus top

Passengers current location and orientation, along with the selected maximum distance and the destination, are sent to the transit web server and routing server. The transit server receives the destination and identifies the nearest bus stop and the associated real-time transit information, and then sends the stop ID to the routing server for walking navigation directions. The transit server then sends a response back to the mobile device. The response is delivered to the user by various feedback mechanisms, such as textual description and a vibration alarm. Figure (5-28) shows the information flow across the four main parts of the system.

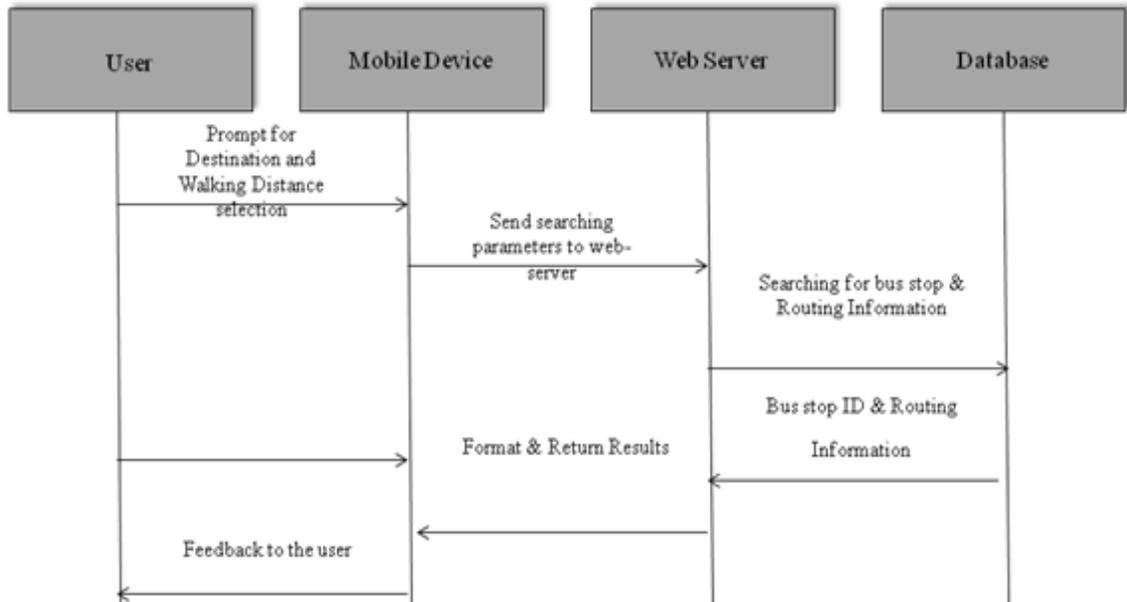


Figure 5-28 Information-flow across the four main parts of the system

This feature can be used where the user is unsure about where the bus stop is, and the user will be alerted when pointing in the direction of the desired bus stop, accompanied by bus timings. So the user is not expected to be beside the bus stop and the stop need not be visible to the user. This can be useful when the user is particularly new to an area and is unsure which bus stop he/she should be at to catch the right bus.

#### 5.8.4 Haptic Feedback-based Model as a Complete System for Transit Services Interaction

To understand how people use public transport, both within their own city and as tourists in other cities where they are not aware of their destination bus stops, a group of fifty transit users were sent an online survey form (Public Transport & I, 2012).

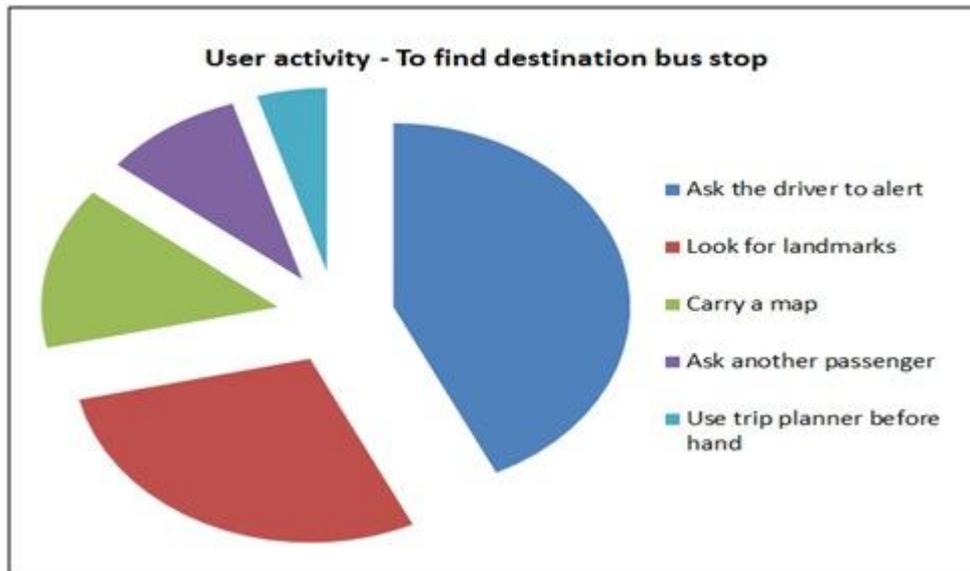


Figure 5-29 User responses to our survey about public transportation usage

We received forty-five responses. The results are presented in Figure (5-29). A total of almost 90% (40/45) of passengers said that they would ask the driver to alert them to their destination stop. The second most popular choice for finding the destination bus stop was to look out for landmarks. A small percentage of passengers said they would use a trip planner before the trip. Based on these results we find that there may be a need to develop a model which can provide passengers with information without the need for asking someone or carrying maps to help.

We have described the development of propose new mobile-based interaction model which provides transit information to the user through haptic feedback. This interaction model (HapticTransit) uses haptics as an alternative interface for the provision of public transport information to passengers with smart phones (Shalaik, et al., 2012a). This work was done in collaboration with my colleague Ricky Jacob where we shared the work regarding real-time transit information and using haptic feedback in pedestrian navigation. Due to the increase in popularity of mobile interaction, our model includes visual interfaces for mobile devices with the addition of haptic-enabled feedback.

To improve the public transport quality of service, passengers must be provided with easy to use, highly accurate and reliable information retrieval systems based on their needs. When using public transportation systems, passengers engage in a series of high-level activities that include planning, waiting and moving (Fischer, G. and Sullivan, J. F. 2002). When the user is on the move, particularly outdoors, a web-based desktop orientated model may not be ideal. In such cases an interaction system specifically developed for mobile clients is very important. As we discussed in Section (5-2), passengers using public transport systems require various information during the main phases in a journey. Our real-time bus tracking system, via its various components such as tracker, predictor and back-end database, provides passengers with various information such as bus current location, estimated time of arrival, and points of interest. Information such as bus stop locations and route geometries are stored in tables within the system database. Passengers want different kinds of information presented in different formats in a trip to suit their needs and the kind of user they are.

#### *5.8.4.1 Pre-Journey Interaction*

At the start of the journey, the user needs information about which is the ideal bus stop to go to, when the next bus should arrive/leave, how to get to the nearest bus stop and how long it should take to get there (Shalaik et al. 2010b). As seen in Figure (5-30), the user's current location is taken to be ( $L$ ). The expected arrival time of the next bus at the origin bus stop  $B_o$  is  $t_o$ . The time taken to walk from the user's current location,  $L$ , to the origin bus stop,  $B_o$ , is denoted as  $t_{wo}$ . This time can be used to advise the user about the appropriate actions to take to catch the next bus at stop  $B_o$ .

The user's actual destination is set to be ( $D$ ). The expected time the bus will take to reach the desired destination bus stop  $B_d$  is  $t_d$ . In a similar manner, the system can compute the time it takes to walk from  $B_d$  to the final destination,  $D$ , this is the time  $t_{wd}$ . Thus, the user can be told how long it will take before they will get to their destination.

The in-bus journey time  $T_j$  is the difference between bus arrival time at the destination bus stop,  $t_d$ , and the bus arrival time at the origin bus stop,  $t_o$ . This is represented as

$$T_j = t_d - t_o \quad (5-1)$$

Thus, the total trip time,  $T$ , is the sum of the walking time from the user's origin to the original bus stop,  $t_{wo}$ , the in-bus journey time,  $T_j$ , and the walking time between the destination bus stop and the actual user destination,  $t_{wd}$ . Thus, we represent the total trip time,

$$T = t_{wo} + T_j + t_{wd} \quad (5-2)$$

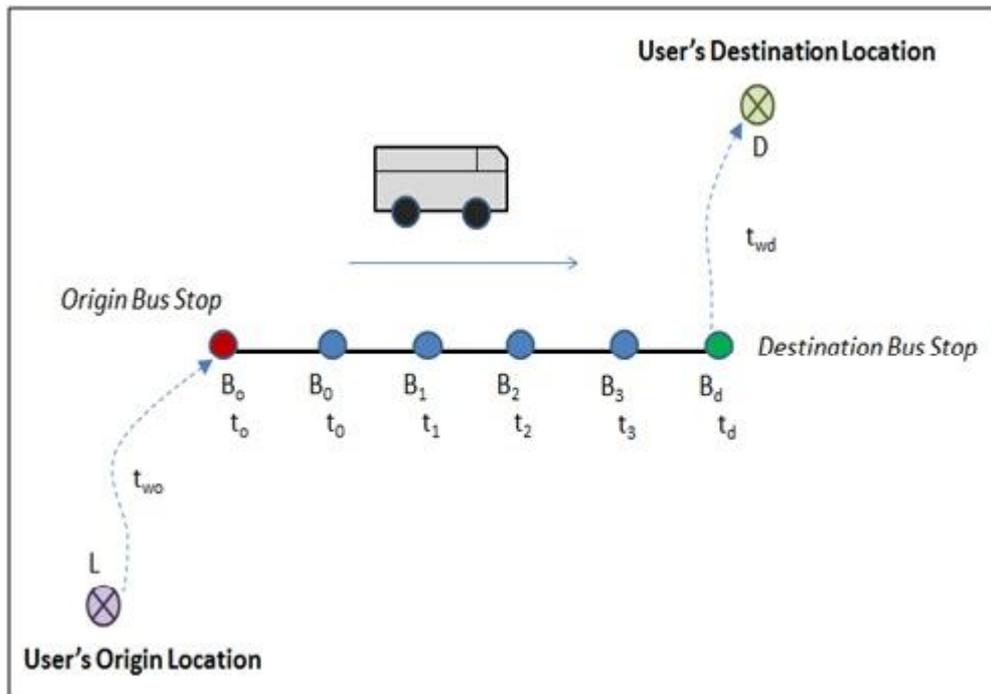


Figure 5-30 Example of how a route and the stops along that route are stored in the database.

If the user has a smartphone and is new to a city or is unsure about which bus stop to go to, they can choose the ‘point-to-query’ element of the system where the user selects the destination and then scans the area to find the general direction of the bus stop  $B_o$ . The “scan” operation is performed as shown in Figure (5-27).

The directional information about the bus stop is provided by textual description with the bus route number and arrival time at the bus stop, along with the walking distance and the time taken to reach the bus stop. Haptic feedback, in the form of

vibration, is used to provide the user with information about the general direction of the bus stop when the user points the smartphone in the direction of the bus stop  $B_o$ . This feature minimises unnecessary interaction with the visual interface while the user walks towards the bus stop, ensuring faster and safer travel.

#### *5.8.4.2 In-Transit Vehicle Interaction*

HapticTransit is a tactile feedback alert/notification model of a system which provides spatial information to the public transport user. The model uses real-time bus locations with other spatial information to provide user feedback about the journey. The system helps passengers to make better use of their time ‘in-transit’. It enables them to get on with other activities without worrying about the arrival at the destination bus stop. Our system provides alerts/feedback which can be of great value to certain user groups. The vibration function is used to provide tactile feedback. Visual feedback in the form of colour-coded buttons and textual description is also provided.

This model can provide the platform to develop such information systems for public transport passengers with special needs – the deaf, the visually impaired and those with poor spatial abilities. The HapticTransit system provides assistance to the user to indicate when they are approaching their destination bus stop. Instead of providing the user with a map-based system, which provides detailed information that may/may not be of use to the user, they are instead notified/alerted using haptic feedback when their stop is approaching. This gives them enough time to prepare to disembark from the bus. Along with the destination, the user may also select the information mode – “destination only” or “tourist mode”. This provides additional assistance with information/alerts about Points Of Interest (POI) along the way using haptic/visual feedback.

The arrival time prediction algorithm is used to ensure that arrival time at their destination bus stop is provided accurately. There is a broker service running on the server responsible for calculating the proximity of the user to their destination bus stop. The visual interface on the device provides the user with the time and distance to the destination stop. The system computes the time and distance to the user's

destination stop and gives a subtle alert to the user when they are nearing the destination. This alert is provided through low frequency vibration feedback. The alert is triggered when the user reaches their penultimate stop. This enables the user to prepare to disembark when the next stop is reached. The intensity of the vibration alert on the mobile device increases as the bus is approaching the desired stop.

As an alternative, the colour-coded button on the visual interface provides the user with information to represent far, close and very close using the red, amber and green colours. A green button indicates that the user still has some distance to travel. An amber button indicates that the user is very close to their destination stop. A red button indicates that the user has reached the penultimate stop. The proposed “HapticTransit” model incorporates additional feedback along the route to improve the in-bus interaction. If the user is a tourist and has selected the option of being informed when they are passing or are near an important POI along the way, he or she is alerted by a unique vibration feedback. Along with haptic feedback, visual feedback with the name and description of the POI is provided. The real-time bus arrival time algorithm computes the arrival time of buses at various bus stops. The haptic feedback ensures that the user is not required to constantly interact or look at the mobile device for assistance during the journey. This allows the user to enjoy the trip and be informed about the destination stop and/or important landmarks along the route.

A model of the route is stored in the database. Consider a route  $R$  as an ordered sequence of stops  $\{B_o, B_0, \dots, B_i, \dots, B_d\}$ , where  $i$  denotes some intermediate stop. The user’s destination bus stop on the route is given by  $B_d$ . Each intermediate stop  $B_i$  has attribute information associated with it, including the stop number and the stop name. Figure 5-21 illustrates this with a sample route where times  $t_0, t_1$  and so on are the times taken to reach stops  $B_0, B_1$  respectively. Using the timetable/real-time bus arrival information for a given journey  $J_R$  along route  $R$ , we store the time at which the bus is expected to reach that stop. The number of minutes it will take the bus to reach an intermediate stop  $B_i$  after departing from  $B_o$  is stored. The actual time of day that a bus on journey  $T_{JR}$  will reach a stop  $B_i$  along the given route  $R$  is also stored.

#### *5.8.4.3 Pedestrian Navigation Phase*

There are two stages in the trip where the user needs pedestrian navigation assistance. To interact with the software, the user has to specify the requirements of their journey and provide information about their destination. The user can then choose which mode of pedestrian navigation they want to use – visual or haptic feedback. Within the haptic feedback option, the user can choose from two pedestrian navigation system options: first, the waypoint by waypoint shortest path information using haptic feedback (R. Jacob, 2011) or second, the destination pointer system where the user is alerted (via vibration) to the general walking direction to the destination (HapticDestinationPointer) (R. Jacob, 2011) and where the user has to make decisions on the path to follow.

### **5.9 Conclusion**

This Chapter outlined the interaction models that passengers can use to access a transit information system. Our public transport software system is accessible through both web-based and mobile-based interfaces. In this chapter, the concept of LBS was discussed and utilized to develop a real-time trip planner system. This system provides door-to-door real-time transit information with information about the predicted arrival time of the next bus, and information about navigation and the time taken to get to the bus stop on foot. Based on the bus arrival time and the time taken for travel the passenger can be advised about when he/she needs to start to walk to the bus stop. This service may help to reduce total trip times as well as waiting time at bus stops. In particular, real-time bus data was used to develop a Location Based Service (LBS) as a smart phone-based application that enables passengers to retrieve real-time location information using their position. New interaction haptic-based interaction models were proposed to improve transport service accessibility. This model exploits the new features of smart mobile phones, such as GPS and digital compass to provide door-to-door journey planning information. In the next chapter, we will discuss techniques by which we tackled uncertainty associated with transit services. We will also discuss the process of developing and evaluating bus arrival times prediction models.

# **Chapter 6 Handling Uncertainty in Real-Time Bus Tracking Systems**

## ***6.1 Introduction***

The most significant source of poor quality services in the transportation sector is caused by the uncertainty associated with the transit service. Handling uncertainty in transport systems should improve transit services which should increase passenger satisfaction. At the heart of our real-time bus tracking systems are methods, algorithms and models to predict bus arrival time at stops along the route. In this research, we discuss and introduce methods to tackle the uncertainty in transport systems, as well as discussing the development and the performance evaluation of bus arrival time prediction models. Two bus arrival time prediction models were developed and a Kalman filter-based bus travel time prediction model was implemented to provide bus passengers with estimated times of arrival. These were compared to determine which was most suitable for our system.

## ***6.2 Types of Uncertainty in Real-Time Bus Tracking Systems***

Two types of uncertainty are frequently associated with transit services provided by real-time bus tracking systems. These are positional uncertainty and arrival time uncertainty. These types of uncertainty may be attributed to the intermittent nature of data transmission or to the inherent errors in GPS positioning. Positional uncertainty is related to the techniques that can be used in determining the bus's current location in terms of the nearest bus stop, whereas the arrival time uncertainty relates to the algorithms and models used to estimate the arrival time at a particular bus stop.

### ***6.2.1 Positional Uncertainty in Real-Time Bus Tracking Systems***

Some positional uncertainty is usually associated with the location of buses when using a location device such as a Global Positioning System (GPS) unit. These vehicles transmit their speed, location as coordinates and other data to a central server. However, rather than raw coordinates, the location is usually better understood in terms of the landmarks along the route, particularly the named stop. In

real-time bus tracking systems, different techniques have been used by different systems in determining a vehicle's location in terms of the distance to a particular bus stop on the route. (Lakshmanan V., 2006) considers the timestamp of GPS data points at or near to a bus stop as arrival times at the bus stops. (Kidwell, 2001) suggests creating artificial "sign-posts" inside the computer software. The software watches the GPS data and sets a flag when the bus has moved close enough to an identified location (such as a bus stop). (Predic et al. 2007) presented the characteristics of realized city bus transit traffic in the city of Niš (Serbia). In their study, the arrival of the vehicle at the bus stop is assumed if a single GPS positional update for that vehicle is detected inside a predefined circular proximity zone and the detected speed is lower than a predefined upper threshold. The reason for this condition is because of the nature and uncertainty associated with GPS data (Edward. K., 2006; Predic et al. 2007).

A more precise condition would be if there are two consecutively detected GPS positional updates within a defined proximity to the bus stop with a speed of 0 km/h. (Bratislav P, et al. 2008). In our public transport software system, efficient algorithms and methods have been implemented to handle and tackle uncertainty in real-time transit vehicle tracking systems (Shalaik, B. and Winstanley, A.C, 2011a). To optimise search efficiency in the bus stop database, a spatial indexing and search strategy can efficiently locate the nearest stop within the database of stops for the route. We create a proximity or zone by defining a numeric value derived from the interval between stops and adding this value to bus location coordinates. For measuring the identity and distance of the nearest bus stop to the moving buses, we calculate the distance between the current location and other stops that are within the created zone.

Figure (6-1) illustrates the measurement of the identity and distance of the nearest bus stop within a predefined proximity. We add a certain degree value to the transit vehicle location (latitude and longitude) to create a circular zone where searching for a bus stop can be performed.

To illustrate this method we provide an example where we add a specific value derived from the interval between the bus stations. This value is added to the latitude

and longitude coordinates of the current location of the transit vehicles, and only stops that are located within this area are retrieved from the database. Then we calculate the nearest stop.

```
Let  $\epsilon = 0.0035$ ; // the derived value from the interval between the
bus stations

Let Bus_Coordinates= {lat, long} // the coordinates of bus current
location

Let BusStop_Coordinates= {latitude, longitude} // the coordinates
of bus stop location

Lat+ = lat +  $\epsilon$ ; // add the epsilon value to the bus latitude;

Lat- = lat -  $\epsilon$ ; // subtract the epsilon value from the bus latitude;

Long+ = long +  $\epsilon$ ; // add the epsilon value to the bus longitude

Long- = long -  $\epsilon$ ; // subtract the epsilon value from the bus
longitude;

// retrieve bus stops from stop table as;

"SELECT * FROM `stop` WHERE `latitude` < Lat+ and `latitude` >
lat_ and `longitude` < long+ and `longitude` > long_";

Then calculate the nearest stop from the retrieved data.
```

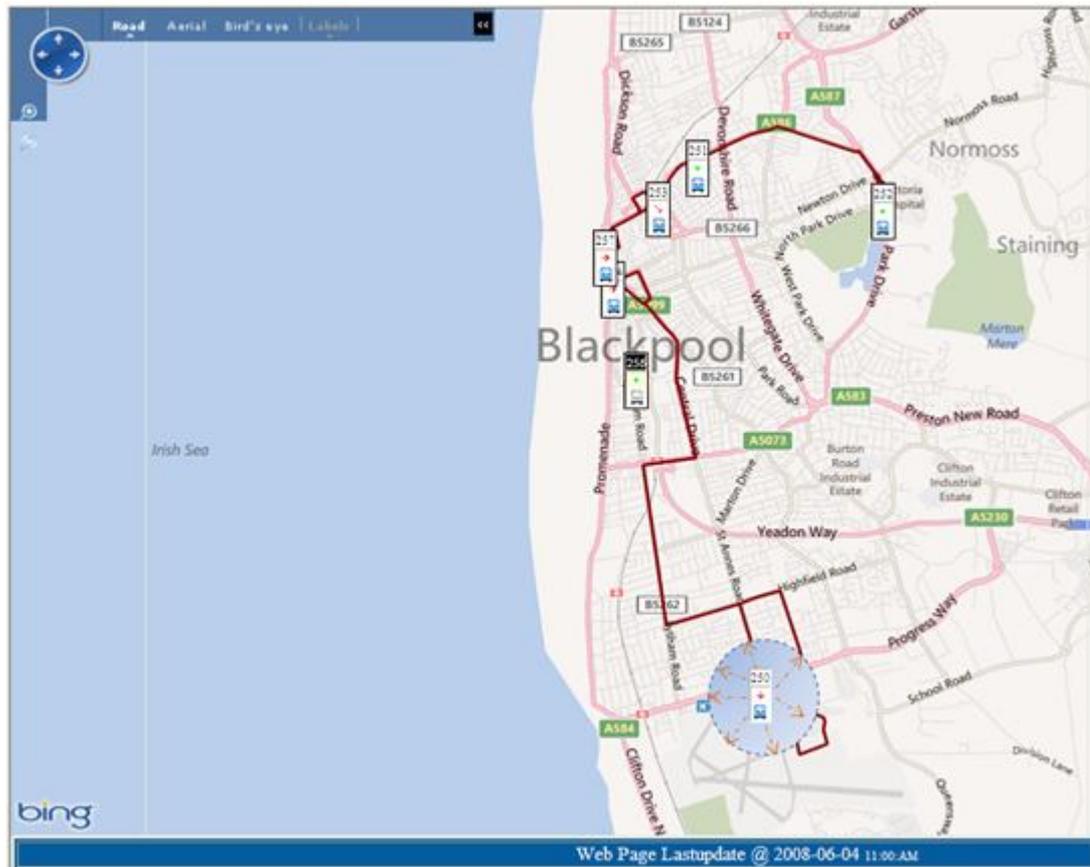


Figure 6-1 Measuring the identity and distance of the nearest bus stop within a predefined area

This method helps to increase search efficiency in the bus stop database as the only stops that are located within this area are retrieved from the database.

### 6.2.2 Arrival Time Uncertainty in Real-Time Bus Tracking Systems

GPS-based AVL systems have been adopted by many transit agencies to track their vehicles and predict arrival times in a real-time environment and provide the public with bus estimated time of arrival/departure. As we discussed and presented in Chapter 2, some research on this topic has been conducted and various prediction models have been developed using different techniques such as Machine learning, Time series modelling, and Kalman filtering however, due to the limitations discussed, more research is required and has to be done to further improve the accuracy of predicted times.

### ***6.3 Transit Vehicle Arrival Times Prediction Models***

Factors such as traffic congestion, weather conditions and random passenger demands make transit vehicles deviate from their timetables, resulting in increasing uncertainty regarding the transit services. Because of the complexity involved, there is a need to develop approaches and algorithms to reduce this uncertainty and predict bus arrival times. An accurate prediction of bus arrival times can help improve the quality of service, attract additional ridership and increase passengers' satisfaction. The development of solid and accurate models to predict bus arrival time requires an integration of different data sources such as traffic data, weather data and passengers demand data. Providing this type of data contributes effectively to the quality and accuracy of these models.

Empirical evidence shows that the time transit users spend outside the transit vehicle (e.g., waiting time at bus stops) is more onerous than the time they spend inside the transit vehicle in motion to their destination. This can be attributed to the uncertainty associated with waiting for a transit vehicle (Ben-Akiva, and Lerman, 1985). In addition, it has been found that providing real-time information significantly increases passenger feelings of safety (Zhang et al, 2008). (Caulfield B., and O'Mahony, M., 2010) in their study evaluating the provision of real-time arrival information for public transit, found that increased satisfaction with public transit leads users to take more transit trips on a weekly basis, spend less time waiting for transit, have increased feelings of personal safety when using transit, and often walk further when using transit. These outcomes are all positive in terms of increasing the use of transit to reduce traffic congestion, reducing the environmental impact of transportation and encouraging the development of communities.

While the provision of real-time information such as bus locations is relatively straightforward, predicting transit information such as when a bus will arrive at a particular location is significantly more complex (Jeong and Rilett 2004). There has been previous research into the prediction of bus arrival times. The methodologies used in previous works include time series models, Artificial Network Models, Kalman filtering models and linear models, among others. These models use different types of data collected from different sources, such as probe vehicle data,

magnetic ticket data, Automatic Passenger Counting (APC) (Shalaby A., Farhan A., 2004; Patnaik.J, S.Chein, and A.Bladihas 2004) and Automatic Vehicle Location (AVL) (Yang, J-S 2005; Seema S.R. and Sheela A., 2009). For the purpose of this study, we developed two bus arrival prediction models, namely a historical-data based model and a multiple linear regression model. Furthermore, we implemented a Kalman filter model for bus arrival time prediction and have evaluated the performance of these models in terms of prediction accuracy. The following sections discuss the process of developing, evaluating and implementing bus arrival time prediction models.

### *6.3.1 Prediction System Architecture*

In our public transport software system, the server has a tracker module and a predictor module as shown in Figure (6-2), the tracker module tracks the current locations of buses. When an update is generated, the tracker updates its state. The predictor module predicts the arrival times for all buses. It has access to the database which stores bus position data as well as additional data such as timestamp, speed, direction and heading for tracking improvement and further processing.

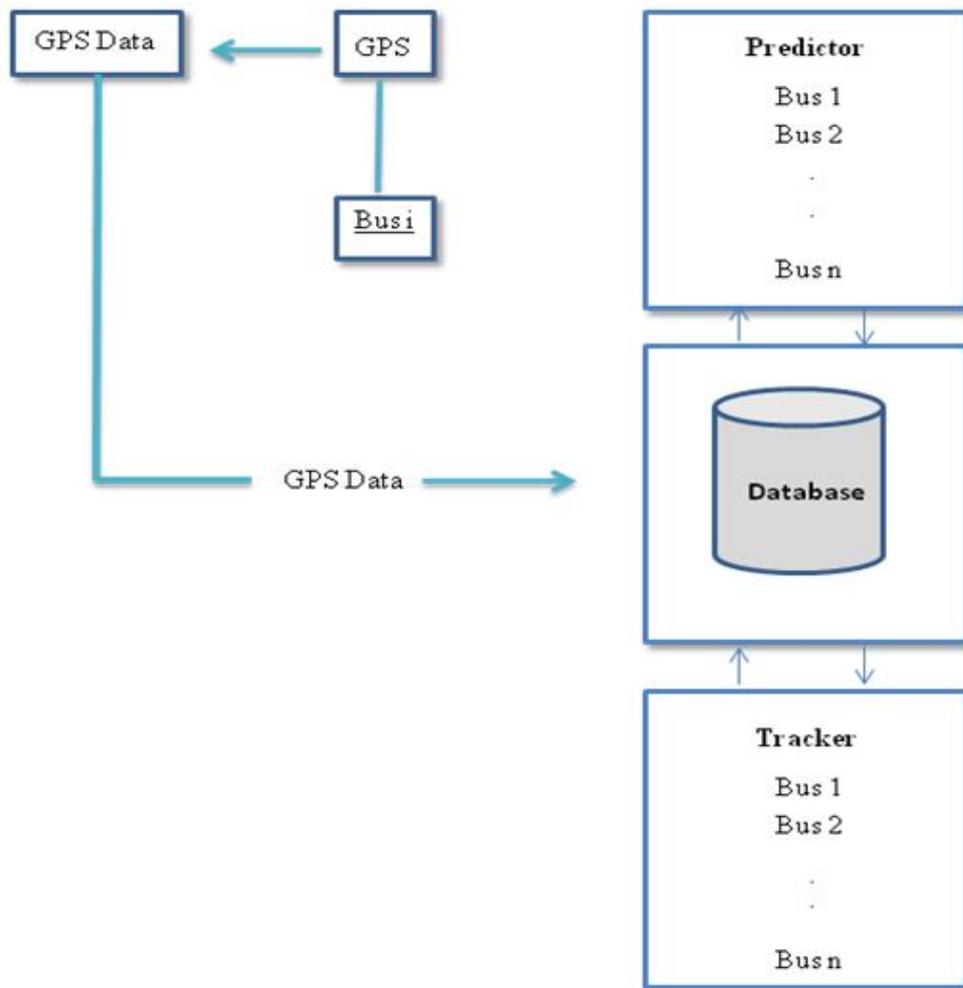


Figure 6-2 Tracker and predictor modules of the real-time bus tracking system

### 6.3.2 Experimental Setup: Blackpool Bus Route 5

The city of Blackpool (Great Britain) lies along the coast of the Irish Sea. It has a population of 142,900, making it the fourth-largest settlement in North West England. The bus services in the city are operated by Blackpool Transport Services. For the purpose of demonstrating the performance of proposed models, Route 5 (one of the busiest bus routes in Blackpool) was selected to be a test case and validation route for developed models. This bus route contains seventy-three bus stops in the north and south directions, fourteen of which are timing-points where departure times are quoted in the public timetable. Figure (6-3) illustrates Bus Route 5 in Blackpool city.

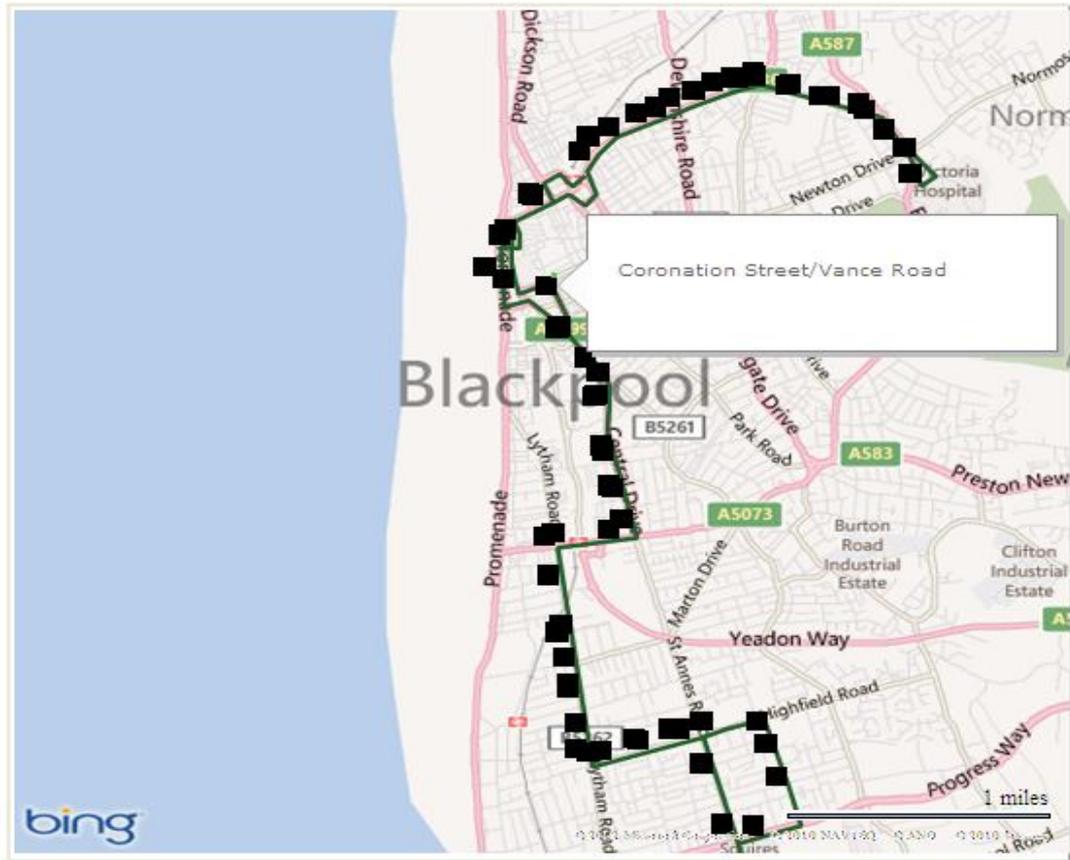


Figure 6-3 Bus Route 5 in Blackpool City

### 6.3.3 Data Collection

The transit vehicles are fitted with a GPS receiver which is integrated with a GSM modem. These units use a standard SIM card as used in mobile phones. The GPS/GSM device records data such as point locations in latitude-longitude pairs, speed, date, time and other information and transmits this data at pre-specified intervals (45 seconds) using the GPS/GPRS module. Figure (6-4) shows the data collection system adopted in this research. As shown in Figure (6-4) a central server accepts this data and stores it in a database.

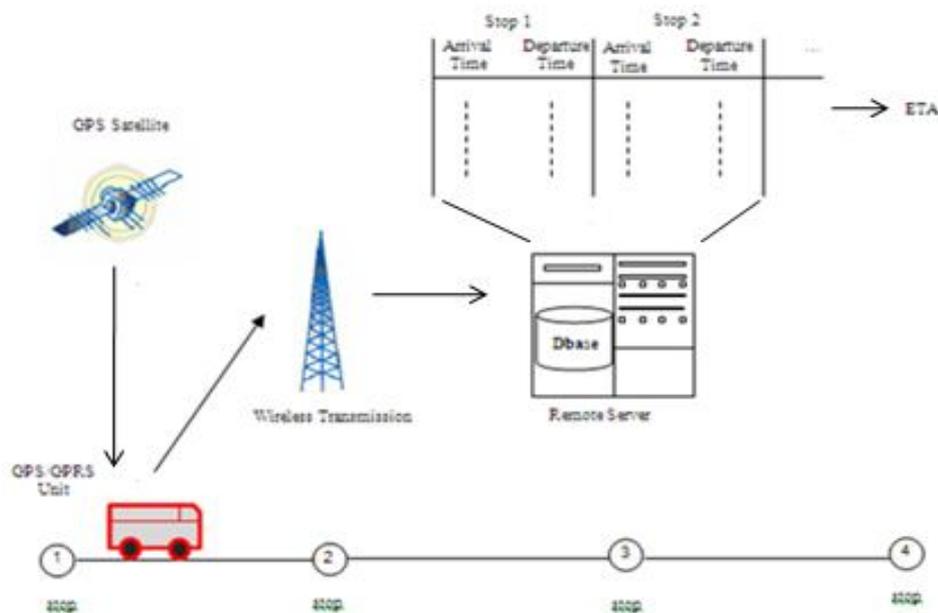


Figure 6-4 Data collection system adopted in this research. (Source: Chung and Shalaby 2007)

Historical travel time data for the study route was collected for developing the prediction models. Real-time bus operational data was then used to evaluate the predictive performance of the developed models.

#### 6.3.4 Description of GPS Data

As outlined in Chapter 2, the GPS system consists of twenty-four satellites and transmits the estimated position, velocity and current time to GPS receivers. Typically, these twenty-four satellites transmit a signal once a second. The location of transit vehicles equipped with GPS can thus be determined every second. However, to analyse data more conveniently, GPS/GPRS systems can be configured to transmit the location data less often. The interval for Blackpool transport data is about forty-five seconds. The GPS data consists of a timestamp, date, latitude, longitude, IMEI or ID, heading, speed, voltage and temperature. The current location and the direction of a transit vehicle can be calculated using the latitude, longitude

and heading in which the transit vehicle is moving. Speed data are calculated by the GPS unit itself. Table (6-1) shows the structure of GPS data used in this research.

Table 6-1 Structure of GPS data

Record	Date Time	Imei	Switch	Event ID	Latitude	Longitude	Speed	Heading	Voltage
2184407	2008-06-28 13:24:24	358279000298263	51	0	53.7748	-3.02596	29.632	250.88	27.5408
2184413	2008-06-28 13:25:28	358279000298263	0	32768	53.7746	-3.02842	18.9645	296.96	27.5499
2184419	2008-06-28 13:25:37	358279000298263	51	0	53.775	-3.02881	25.4835	343.04	27.5068
2184420	2008-06-28 13:25:42	358279000298263	0	43	53.7753	-3.02893	23.113	345.6	27.5068
2184425	2008-06-28 13:25:54	358279000298263	51	0	53.776	-3.02913	29.0394	353.28	27.5169
2184434	2008-06-28 13:26:00	358279000298263	51	0	53.7765	-3.02932	30.8173	340.48	27.5337
2184435	2008-06-28 13:26:12	358279000298263	0	32811	53.777	-3.0298	24.2982	271.36	27.5337
2184444	2008-06-28 13:26:34	358279000298263	51	0	53.7774	-3.03217	35.5584	343.04	27.5362
2184445	2008-06-28 13:26:35	358279000298263	0	43	53.7775	-3.03221	35.5584	343.04	27.5362
2184450	2008-06-28 13:26:39	358279000298263	51	0	53.7778	-3.03239	36.151	340.48	27.4834
2184458	2008-06-28 13:26:56	358279000298263	0	32768	53.7789	-3.033	1.77792	340.48	27.0461
2184464	2008-06-28 13:26:39	358279000298263	51	0	53.7778	-3.03239	36.151	340.48	27.2122
2184475	2008-06-28 13:27:28	358279000298263	0	32768	53.7789	-3.03298	0	58.88	27.3046
2184487	2008-06-28 13:27:51	358279000298263	51	0	53.7798	-3.03353	32.0026	332.8	27.3498
2184494	2008-06-28 13:28:27	358279000298263	0	32768	53.7802	-3.0338	0	207.36	27.426
2184502	2008-06-28 13:28:54	358279000298263	51	0	53.7802	-3.0338	0	240.64	27.4164
2184511	2008-06-28 13:28:56	358279000298263	0	32768	53.7802	-3.0338	0.59264	337.92	27.5555

For various reasons, such as tall buildings or losing the GPS fix, missing data can occur. Missing data are replaced using the linear interpolated method (Ogle *et al.* 2002) according to the distance between the nearest two observed data points. That is, we artificially create a data point between any two points. In Figure (6-5) there are missing data between  $GD_{i-1}$  and  $GD_{i+1}$ . As seen from Figure (6-5) The location of  $GD_i$  can be determined using interpolation according to the distance between two observed data points,  $GD_{i-1}$  and  $GD_{i+1}$ , with the assumption that the travelling speed between  $GD_{i-1}$  and  $GD_{i+1}$  is constant. We use equation (6-1) to perform a linear interpolation.

$$T_i = T_{i-1} + \left( \frac{X_{i-1,i}}{X_{i-1,i+1}} * (T_{i+1} - T_{i-1}) \right)$$

(6-1)

Where:

$X_{i-1,i+1}$  is the distance between  $GD_{i-1}$  and  $GD_{i+1}$

$X_{i-1,i+1} = X_{i-1,i} + X_{i,i+1}$

$T_i$  is the GPS timestamp of  $GD_i$

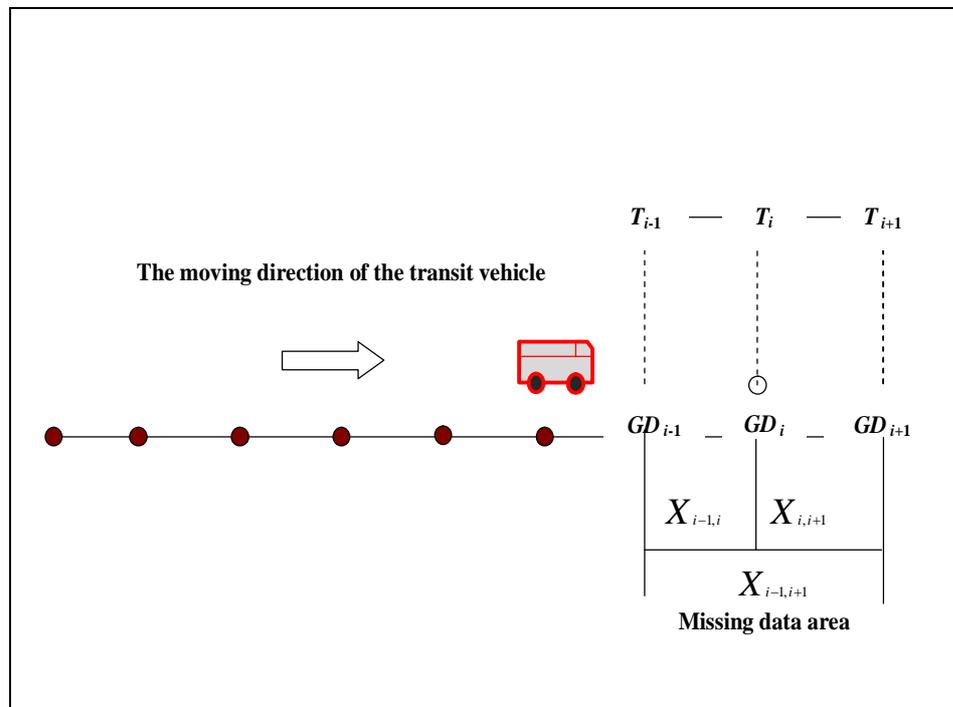


Figure 6-5 GPS missing data between bus stops

### 6.3.5 Bus Arrival Times Determination at Bus Stop

As discussed in Section (6.2.1), different methods are used in real-time bus tracking systems to determine or announce bus arrival at bus stops. In our public transport software system, the GPS time of the nearest location data from each bus stop (the shortest distance from the bus stop) is considered as the arrival time at the stop. Even if a bus sometimes does not stop due to an absence of passenger demand, the GPS

time of the nearest location data from each bus stop is considered as the arrival time at the stop. In other words, regardless of whether a bus stops at a bus stop or not, the basic principle of determining the arrival time is that the GPS time of the nearest location data from each bus stop is considered as the arrival time at the stop.

### 6.3.6 Historical Data-Averaging Model

The historical data model predicts travel time using the average travel time for the same journey over similar conditions obtained from the data archive. This model assumes that traffic conditions are cyclical and that the usual travel time on a specific route is a good predictor of future journey times today. However, it requires sufficient observations (samples) to produce meaningful results. In order to consider traffic congestion and different travel patterns, we average bus travelling time (between bus stops) for the same day of the week (week day/weekend) and same time of the day (peak-time/non-peak-time) with the underlying assumption that buses will be running in similar operational conditions at the same time each week.

The input to the historical data averaging model is day of the week, time of the day and origin and destination bus stops.

$$\eta = \sum_{i=1}^N \text{traveltime}_i \quad (6-2)$$

Where:  $\eta$  = mean travel time.

*traveltime* is bus travel time between bus stops

### 6.3.7 Kalman Filtering Models

Kalman filtering is an efficient procedure that estimates the future states of dependent variables. The purpose of a Kalman filter is to estimate the state of a system from measurements that contain random errors. The Kalman filter is a multi-dimensional model based on the numbers of state variables to be estimated. We used one parameter (last observed bus running time) as the state variable. One of the main characteristics of a Kalman filter is its ability to update itself based on new data that reflect the changing characteristics of the vehicle operating environment. Bus travel time between stops was modelled to predict arrival times along the bus route.

This model makes use of the historical data on bus running times for the instant  $(k+1)$  as well as the bus running time for the previous bus on the current day at the instant  $(k)$  to predict the bus running time at  $k+1$ . The algorithm works conceptually as follows: the last number of days (for example three days') historical data of Actual Running Times (*art*) between stops at the instant  $(k+1)$  plus the running time observation at the instant  $(k)$  on the same day are used to predict bus running time at the instant  $(k+1)$ . Generally, a Kalman filter for bus link running time has the following structure (Reinhoudt and Velastin 1997):

$$g(k+1) = \frac{e(k) + \text{Var}[data_{out}]}{\text{Var}[data_{in}] + \text{Var}[data_{out}] + e(k)}$$

(6-3)

$$a(k+1) = 1 - g(k+1)$$

(6-4)

$$e(k+1) = \text{VAR}[data_{in}]g(k+1)$$

(6-5)

$$p(k+1) = a(k+1)art(k) + g(k+1)art_1(k+1)$$

(6-6)

where

- $g(k)$  equals the filter gain at instant  $k$
- $a(k)$  is the loop gain at instant  $k$
- $e(k)$  represents filter error at instant  $k$
- $p(k)$  equals prediction at instant  $k$
- $art(k)$  is the actual running time of the previous bus at instant  $k$
- $art_1(k+1)$  is the actual running time of the previous day at instant  $k+1$
- $\text{VAR}[data_{out}]$  equals the prediction variance of *data*
- $\text{VAR}[data_{in}]$  is variance of *data* for the last three days

The input variance  $VAR[data_{in}]$  is calculated at each instance  $k+1$  using the actual running time values of the last three days:  $art_1(k+1)$ ,  $art_2(k+1)$ , and  $art_3(k+1)$ :

$$VAR[data_{in}] = VAR[art_1(k+1), art_2(k+1), art_3(k+1)]$$

(6-7)

where:

$art_1(k+1)$  is the actual running time of the bus at instant  $(k+1)$  on the previous day

$art_2(k+1)$  is the actual running time of the bus at instant  $(k+1)$  on the previous two

days

$art_3(k+1)$  is the actual running time of the bus at instant  $(k+1)$  on the previous three

days

The definition of the variance of a random variable is:

$$VAR[X] = E[(X - E[X])^2]$$

(6-8)

and the expectation operator is

$$E(X) = Avg(art) = \frac{art_1(k+1) + art_2(k+1) + art_3(k+1)}{3}$$

(6-9)

Now the variance can be calculated as shown in equation (6-13)

$$\Delta_1 = [art_1(k+1) - avg(art)]^2$$

(6-10)

$$\Delta_2 = [art_2(k+1) - avg(art)]^2$$

(6-11)

$$\Delta_3 = [art_3(k+1) - avg(art)]^2$$

(6-12)

giving

$$VAR[data_{in}] = \frac{\Delta_1 + \Delta_2 + \Delta_3}{3}$$

(6-13)

$VAR[data_{out}]$  is based on the model prediction output and the corresponding future observation. Both pieces of data are not available, since the prediction has not been made yet and the future trip has not been made either. Ideally,  $VAR[data_{out}]$  should be equal to  $VAR[data_{in}]$  for good prediction performance (Maybeck, 1979). Now, a new variance is introduced  $VAR[local_{data}]$ . It is equal to the variance of the input and output data.

$$VAR[local_{data}] = VAR[data_{in}] + VAR[data_{out}]$$

(6-14)

and equation (6-3) and equation (6-5) become:

$$g(k+1) = \frac{e(k) + VAR[local_{data}]}{e(k) + 2VAR[local_{data}]}$$

(6-15)

$$e(k+1) = VAR[local_{data}]g(k+1)$$

(6-16)

Now it becomes easy to implement the actual Kalman filter algorithm to predict the bus running times along the links. The order of applying the equations should be (6-15), (6-4), (6-16) and (6-6).

### 6.3.7.1 Numerical Example

Consider a case in which we want to predict the bus running time for the next trip at 10:15, instant  $(k+1)$ , and that the observed running time  $art(k)$  of the previous bus (i.e. at time 10:00) is 300 seconds, which could be known directly from the AVL system, and the historical actual running times of the last three days at instant  $k+1$  (i.e. at time 10:15) are  $art_1 = 400$ ,  $art_2 = 420$  and  $art_3 = 380$  seconds. We calculate the mean and variance as:

$$Average = \frac{400 + 420 + 380}{3} = 400 \text{Seconds}$$

$$\Delta_1 = (400 - 400)^2 = 0$$

$$\Delta_2 = (420 - 400)^2 = 400$$

$$\Delta_3 = (380 - 400)^2 = 400$$

$$\text{VAR}[\text{localdata}] = \frac{\Delta_1 + \Delta_2 + \Delta_3}{3} = \frac{800}{3} = 266.66$$

Now, to predict the running time for the current day bus  $p(k+1)$  (i.e. at time 10:15), the Kalman Filter equations (6-15), (6-4), (6-16) and (6-6) are used. First, to calculate the value of  $g(k+1)$  from equation (6-15), we need the value of the VAR [local data] for the instant of prediction  $k+1$  (i.e. 10:15), which is equal to 266.66 and the value of the  $e(k)$ , which we assume is equal to 72.40 (from the previous bus prediction at time 10:00).

$$g(k+1) = \frac{72.40 + 266.66}{72.40 + 2 * 266.66} = 0.56$$

The value of  $a(k+1)$  is then calculated using equation (6-4).

$$a(k+1) = 1 - 0.56 = 0.44$$

Now we calculate the value of  $e(k+1)$  so that it can be used for the next step prediction ( $k+2$ ). The value of  $e(k+1)$  is equal to  $g(k+1)$  multiplied by Var [local<sub>data</sub>].

$$e(k+1) = 266.66 * 0.56 = 149.32$$

With the above calculations made, the predicted running time at instant  $k+1$  (i.e. 10:15) can be calculated using equation (6-6). The prediction value of  $p(k+1)$  is mainly based on the running time value of the previous bus  $art(k)$ , (i.e. the 10:00 bus) on the current day and the value of the running time  $art_j(k+1)$ , (i.e. the 10:15

bus) on the previous day, with each value multiplied respectively by the dynamic weights  $g(k+1)$  and  $a(k+1)$ , which are updated in each new prediction step thus,

$$p(k+1)=0.44*300+0.56*400= 356 \text{ Seconds}$$

The value of 356 seconds represents the predicted bus running times along the links which can be added to bus's departure time to calculate bus's arrival time.

### *6.3.8 Linear Regression Models*

Linear regression is the first type of regression analysis to be used extensively in practical applications (Gurmu Z., K., (2010). For bus travel time prediction, linear regression is used to model the relationship between the estimated bus travel times (dependent variable) and the impact factors (independent variables). These models predict a dependent variable with a mathematical function formed by a set of independent variables. This requirement for independent variables limits the applicability of the regression model in transportation because variables in transportation systems tend to be highly inter-correlated. However, a travel time estimation model can be developed as a function of several significant variables (for example, bus average speed, distance between bus stops, number of intermediate stops and time of day, etc). We used multiple linear regression methods to construct a formula that will predict travel time values between bus stop  $i$  and bus stop  $j$  ( $TT_{ij}$ ) from variables such as (1) the remaining number of bus stops from the current bus stop to the target bus ( $BS_{ij}$ ), (2) the remaining distance from the current bus stop to the target bus stop in km ( $D_{ij}$ ) and (3) the average speed from the origin of the route to the current stop ( $S_{oi}$ ).

Multiple Linear Regression (MLR) is a form of regression analysis in which the relationship between one or more independent variables and another variable, called the dependent variable, is modelled by a least squares function, called a linear regression equation. The least square method is used to estimate regression

parameters and these were applied to calculate a predicted travel time. The three selected independent variables (the number of stops between the origin and target stop, the distance between origin and target stop and speed of transit vehicle,) were each tested to see if they showed a linear relationship with the travel time and thus if they had a high correlation with the dependent variable.

To visualise the relationship between each of the independent variable and the dependent variable that is, the travel time, we used a scatter plot. Figure (6-6) shows the scatter plot of  $BS_{ij}$  and  $TT_{ij}$ . We used the correlation coefficient (Joseph L. R., and Alan N. W., (1988) as a measure of the strength of the straight-line or linear relationship between two variables. The correlation coefficient's value is 0.918, which indicates an almost perfect positive linear relationship, as the number of bus stops between the current bus stop and the target bus stop increases so the travel time between the bus stops increases.

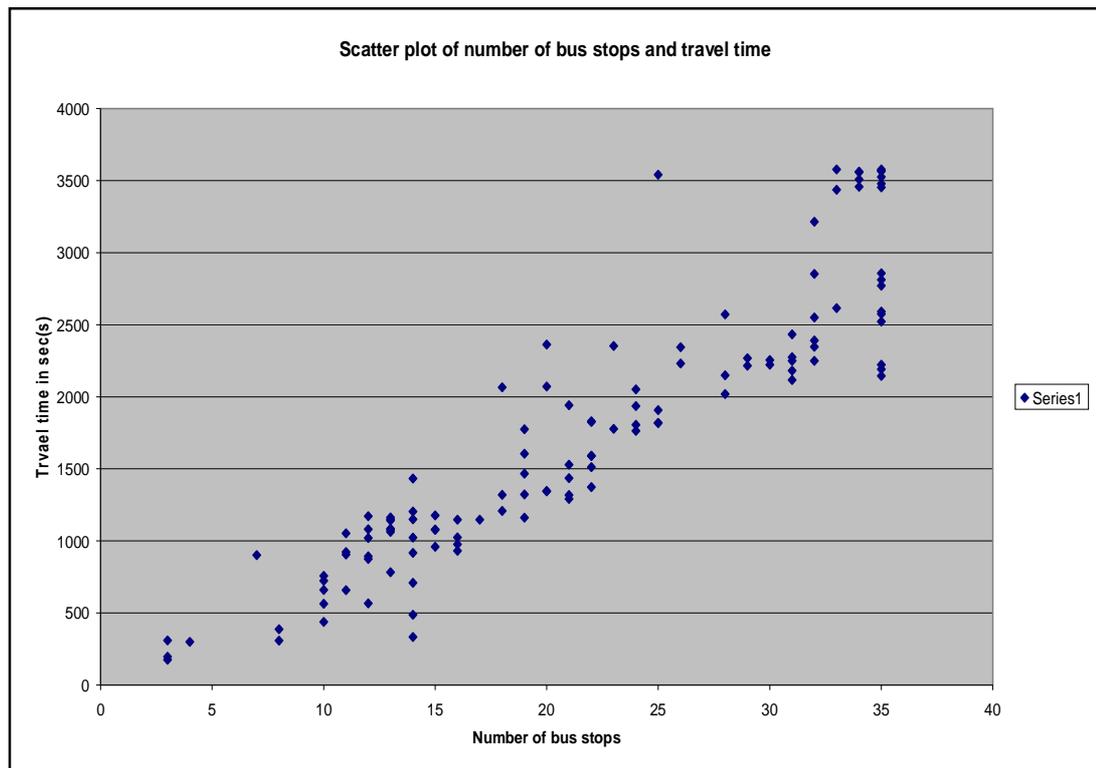


Figure 6-6 Scatter plot of travel time and the remaining number of stops between current stop and the target stop

The correlation coefficient between the remaining distance between bus stop  $i$  and bus stop ( $D_{ij}$ ) and travel time is high (0.840), and the scatter plot in Figure (6-7) shows the linear relationship between these two variables.

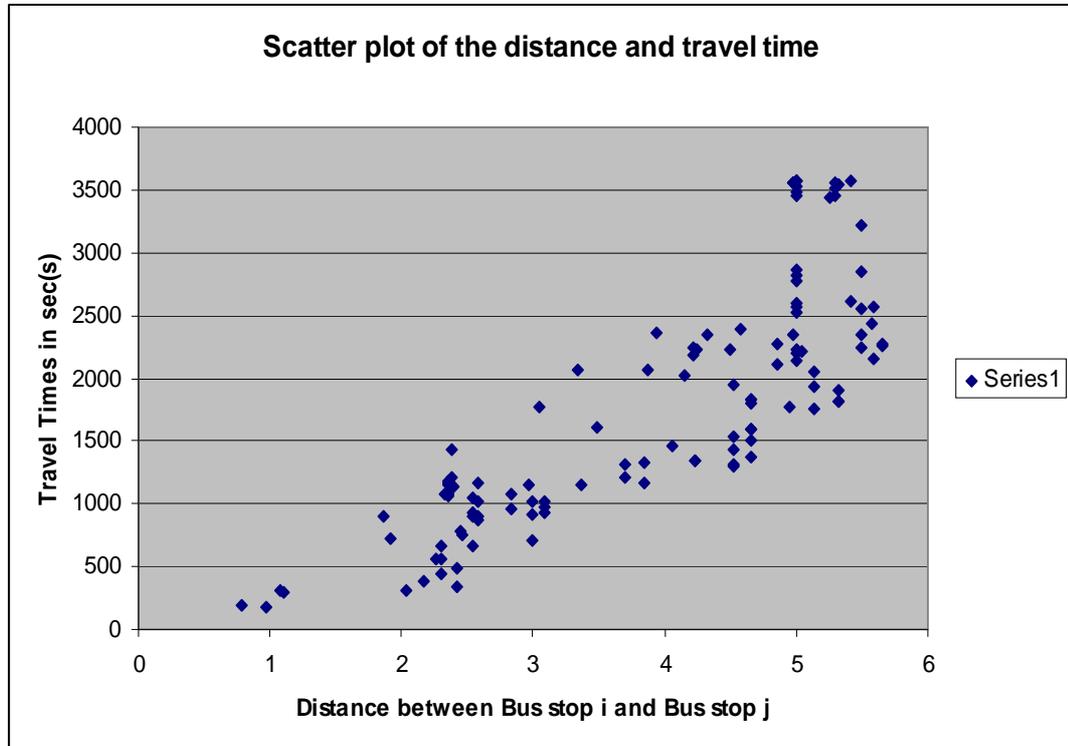


Figure 6-7 Scatter plot of travel time and distance between current stop and the target stop

There is a moderately negative linear relationship between the travel time and average speed ( $S_{ij}$ ) from the original bus stop and the current bus stop. The correlation coefficient value is -0.735, indicating that as speed increases, travel time decreases. Figure (6-8) shows a scatter plot of travel time and bus average speed variables.

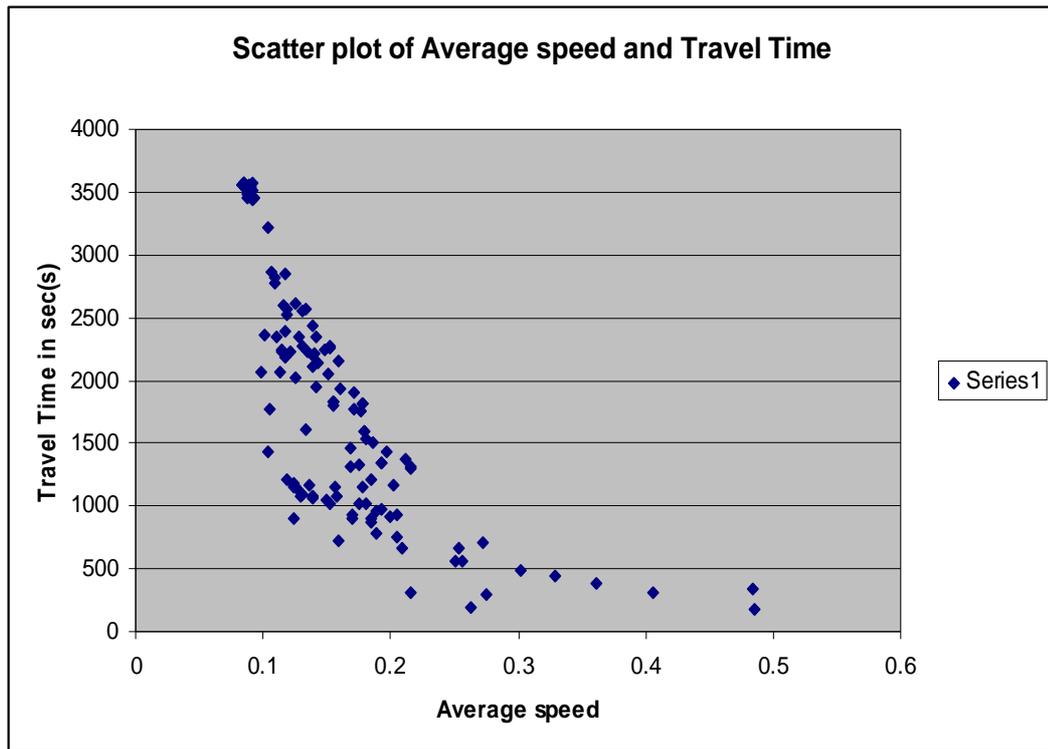


Figure 6-8 Scatter plot of travel time and bus average speed variables.

The three independent variables  $BS_{ij}$ ,  $S_{oi}$ , and  $D_{ij}$  were used to develop the (MLR) and from this to develop a travel time prediction model. The best model developed was as follows:

$$TT_{ij} = 710 + 67.5BS_{ij} + 37D_{ij} - 3631S_{oi} \quad (6-16)$$

In linear regression model, the regression coefficients or effects are estimated from the data, and computed by the regression tool. They are values, one for each independent variable, that represent the strength and type of relationship the independent variable has to the dependent variable. When the relationship is positive, the sign for the associated coefficient is also positive. Coefficient for negative relationship have negative signs. When the relationship is a strong, the coefficient is large. Weak relationships are associated with coefficient near zero.

The explanatory power of the regression model is summarised by its “R-squared” value. R-squared or (Coefficient of determination) is often described as the proportion of variance explained by regression and indicates how “good” the regression is in terms of fitting the calibration data. If the regression is perfect the R-squared is 1. If the regression is a total failure, no variance is explained by the regression and R-squared is zero. R-squared, often called the coefficient of determination, is defined as the ratio of the sum of squares explained by a regression model and the "total" sum of squares around the mean and can be calculated using this formula (www.radicalmath.org, 2012):

$$R - Sqaured = \frac{\text{Sum of squared distances between the actual and predicted values}}{\text{Sum of squared distances between the actual values and their mean}}$$

The *R-Squared* value for this model is 0.8901, which indicates a very good model fit and a high overall predictive accuracy of this multiple regression model. The interpretation of R-square is "The amount of variance in the dependent variable that can be explained by the model" (Patnaik.J, S.Chein,and A.Bladihas, 2004). The closer to 1.0 the *R-squared* value is, the better the model. The closer the *R-squared* value is to 0, the worse the model.

### 6.3.9 Performance Evaluation of Prediction Models

These three prediction models (a historical-data-averaging model, a Kalman filtering model and a multiple linear regression model) have been tested using three different datasets described in Section (6.3.4) so their prediction performance could be evaluated. Table 6-2 shows in seconds the values of predicted arrival times against the actual values for the first test dataset.

Table 6-2 Actual arrival times against predicted arrival times for the first testing dataset

Actual Arrival in sec(s)	K.F. Model	Historical-data Model	M.L.R Model
2507	2373	2037	2099
2472	2335	1997	2034
2377	2297	2166	1969
2292	2237	2092	1904
2196	2131	1964	1774
2093	1958	1632	1709
1697	1794	1837	1644
1527	1630	1905	1579
1425	1515	1230	1514
1376	1440	1164	1449
1302	1347	1284	1384
1243	1298	1442	1319
1195	1226	1377	1254
1121	1186	935	1189
1076	1073	1381	1124
895	880	837	1059
796	842	671	994
651	693	898	799
529	575	855	734
447	389	328	539
402	352	282	474
352	285	237	409
299	234	184	344
158	138	106	279
124	62	63	214
2391	2237	2092	1904
2334	2169	2047	1839
1761	1822	1837	1644
1619	1636	1905	1579
1489	1486	1230	1514

To quantify the prediction error and assess the predictive performance of the three prediction models, Mean Absolute Percentage Error (MAPE) (Makridakis, S., 1993; Ren, L. and Glasure, Y. (2009) was used as a measure of closeness between the predicted and observed or actual arrival times.

$$MAPE = \frac{1}{n} \sum_i^n \left| \frac{y_p - y_{ob}}{y_p} \right| \times 100\% \quad (6-17)$$

Where:

$y_p$  = Predicted travel time.

$y_{ob}$  = Observed travel time.

$n$  = Number of validation data points.

MAPE represents the average percentage difference between the observed value (in this case observed arrival times at a bus stop) and the predicted value (in this case predicted arrival times at a bus stop). A Smaller MAPE value means that particular model predictions are more accurate than those of the other models. The plots of observed bus arrival times versus predicted values of Kalman filtering, Historical data average and MLR models for the first testing dataset are presented in Figure (6-9), Figure (6-10) and Figure (6-11) respectively.

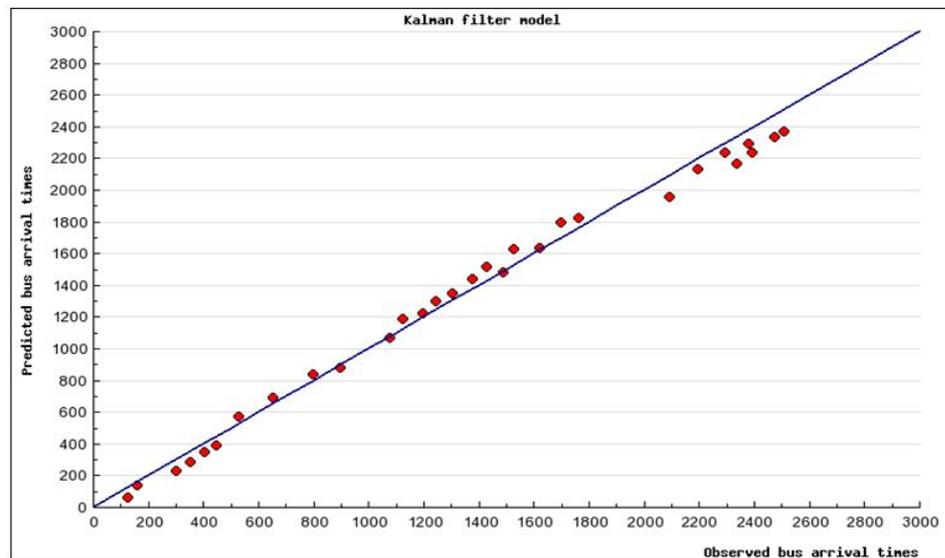


Figure 6-9 Predictability of Kalman filtering model for the first test dataset

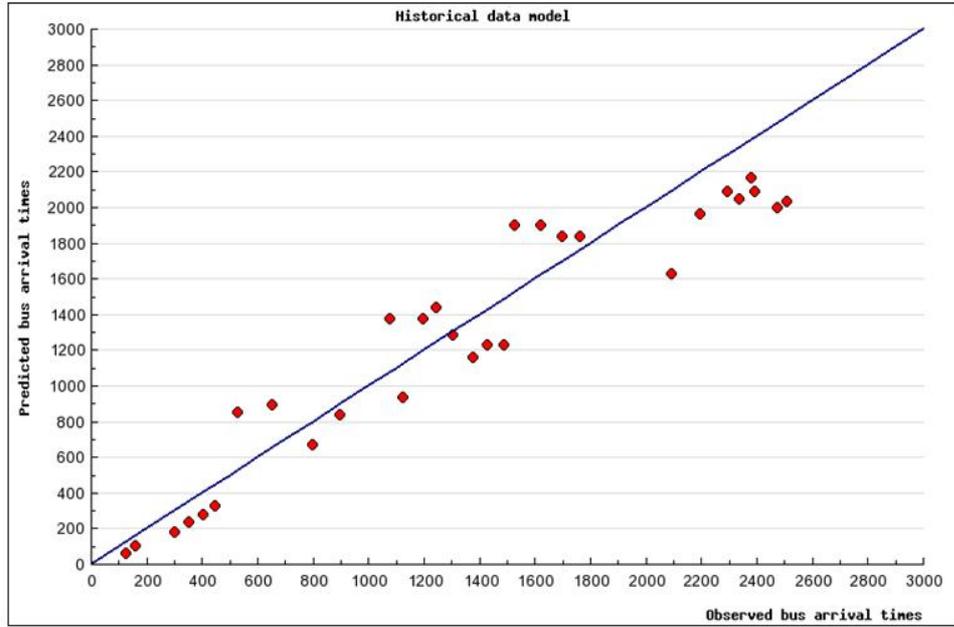


Figure 6-10 Predictability of the Historical data model for the first test dataset

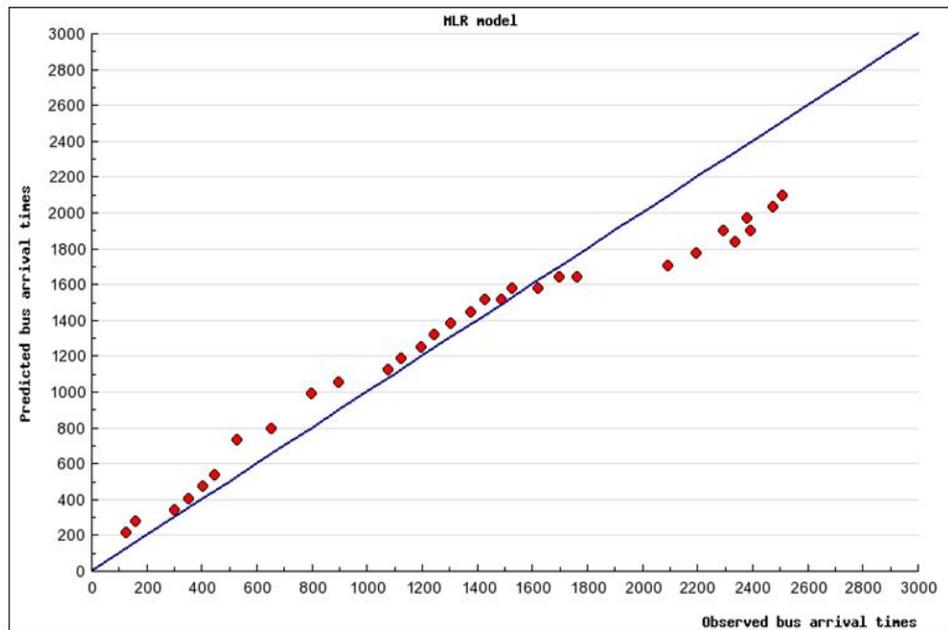


Figure 6-11 Predictability of the MLR model for the first test dataset

Figures (6-9), (6-10) and (6-11) show scatter plots of the observed arrival times values on the x axis versus the predicted values of arrival times on the y axis. The values are measure in seconds. The diagonal line shows the correlation between the

predicted and the observed values. When the two values are close to the diagonal line (observed= predicted) is an indicator for perfect correlation.

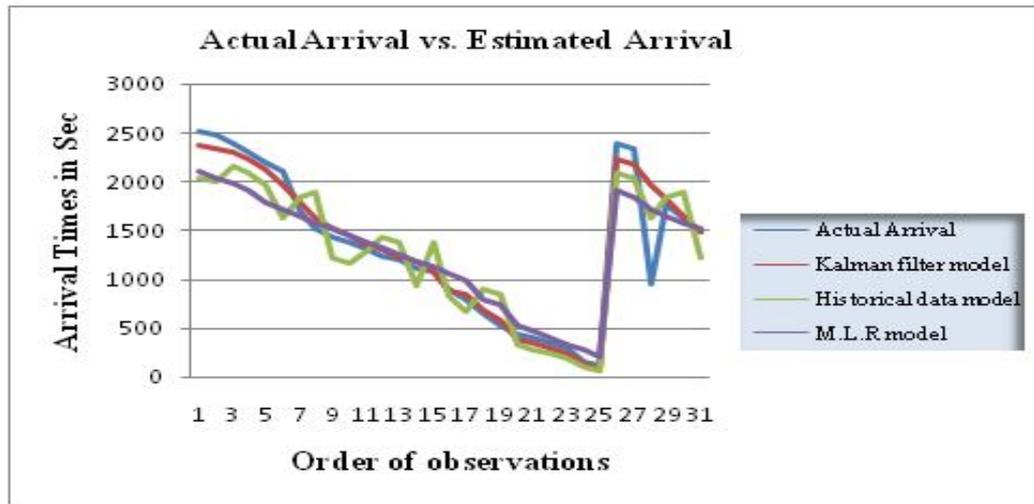


Figure 6-12 Predictability of the three prediction models for first test dataset

The travel time prediction process begins when transit vehicle begins to move from their current location to the nearest main stop, where less travel time as the bus approached the station where the prediction process starts again and this explains the shape in Figure (6-12).

It can be seen from the Figures (6-9), (6-10), (6-11) and (6-12) that the results of Kalman filtering model are much closer to the observed values than the other two models which means that Kalman filtering model provided better prediction results. It can be observed from Figure (6-12) that the Kalman filtering model has less prediction errors compared to the other two models.

In Table (6-3), the MAPE results of the three models are shown. The Kalman filter model has the smallest value of MAPE and outperformed the MLR model and historical-data model.

Table 6-3 MAPE values of three prediction models for the first test dataset

Model	MAPE
Kalman Filter Model	3.5 %
Historical-data Averaging Model	7.8 %
Multiple Linear Regression Model	5.1 %

Table (6-4) shows the observed arrival times against the predicted values for the second test dataset.

Table 6-4 Actual arrival times against predicted arrival times for the second test dataset

Actual Arrival in sec(s)	K.F. Model	Historical-data Model	M.L.R Model
1391	1436	1164	1449
1311	1318	1442	1319
1249	1226	1377	1254
1201	1188	935	1189
1084	1081	1381	1124
1009	899	837	1059
885	828	843	929
842	695	898	799
714	571	855	734
632	525	648	669
525	391	381	604
487	356	328	539
411	337	282	474
345	260	237	409
303	201	184	344
135	144	106	279
446	448	461	692
352	343	353	562
312	295	295	497
210	205	183	302
157	140	115	172
186	92	61	172
1550	1428	1593	1319
1504	1393	1328	1254
1370	1328	1267	1189
1300	1269	1183	1124
1206	1174	1069	994
1020	1010	898	929
625	696	685	864
437	595	545	799
379	532	461	734
347	439	414	669
246	349	353	604

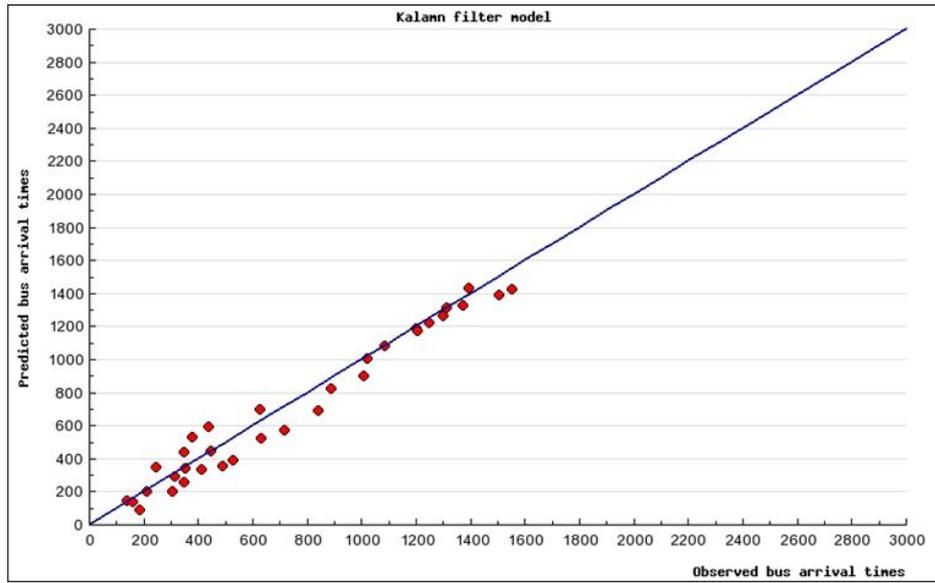


Figure 6-13 Predictability of Kalman filtering model for the second test dataset

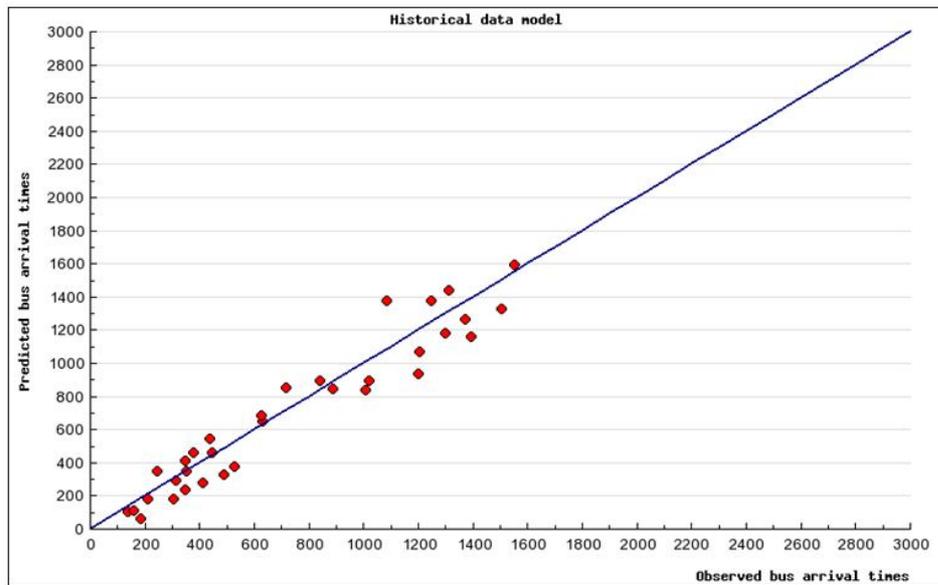


Figure 6-14 Predictability of Historical data model for the second test dataset

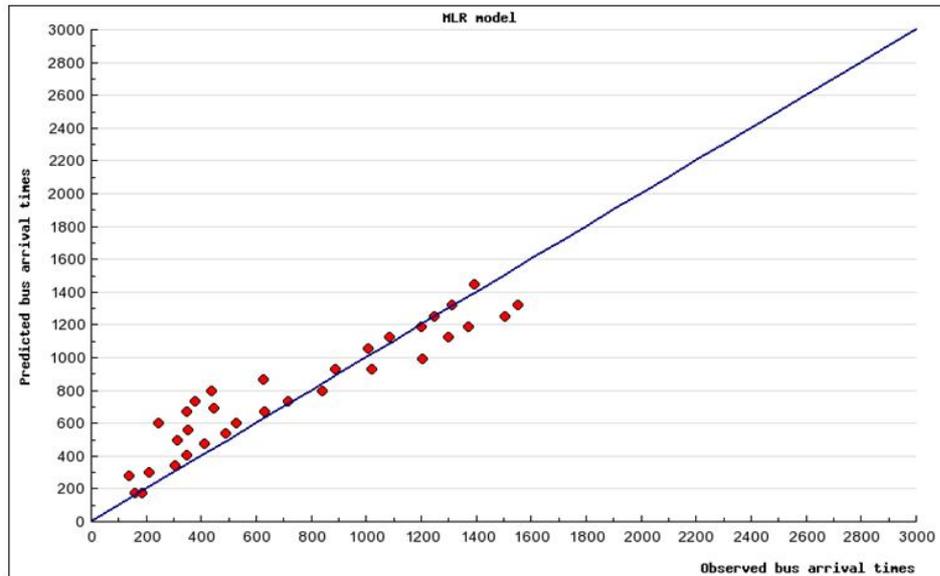


Figure 6-15 Predictability of MLR model for the second test dataset

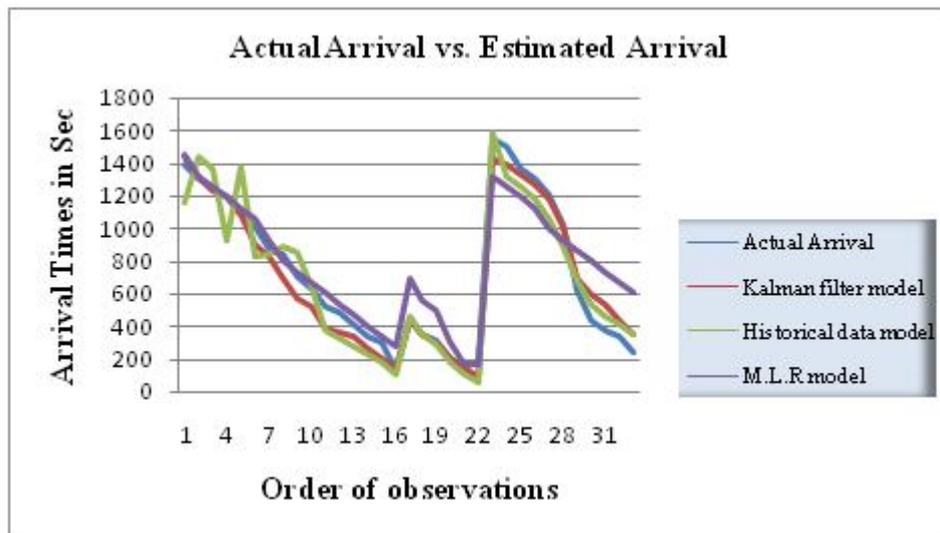


Figure 6-16 Predictability of the three prediction models for the second test dataset

For the second test data set, the Kalman filtering model outperformed the other two models and provides better prediction results as observed in Figures (6-13), (6-14), (6-15). By comparing prediction errors of the three models, it can be observed in Figure (6-16) that the Kalman filter model has the smallest magnitude of prediction errors. MAPE results derived from the second test data set are presented in Table 6-5. The Kalman filter model has the smallest value of MAPE. It also shows some improvement in the prediction performance of the MLR model.

Table 6-5 MAPE values of three prediction models for the second day's testing dataset

<b>Model</b>	<b>MAPE</b>
Kalman Filter Model	5.4 %
Historical-data Averaging Model	8.2 %
Multiple Linear Regression Model	6.3 %

For the third test dataset, the observed arrival times against the predicted arrival times are shown in seconds in Table 6-6.

Table 6-6 Actual arrival times against predicted arrival times for the third testing dataset

Actual Arrival in sec(s)	K.F. Model	Historical-data Model	M.L.R Model
218	279	295	539
123	219	220	409
78	174	158	279
782	890	898	845
633	598	685	780
493	511	545	715
436	375	461	650
388	406	414	585
267	291	353	520
222	204	274	390
139	156	183	260
73	110	115	130
1948	2060	1999	1969
1886	1937	2125	1839
1816	1852	2063	1774
1708	1729	1962	1579
1681	1705	1905	1514
1546	1544	1952	1384
1481	1429	1593	1319
1408	1395	1328	1254
1350	1331	1267	1189
1302	1271	1183	1124
1182	1176	1069	994
941	1013	898	929
624	700	685	864
512	598	545	799
452	535	461	734
377	442	414	669
279	349	353	604
231	279	295	539
184	219	220	409
45	124	115	214
41	46	61	130

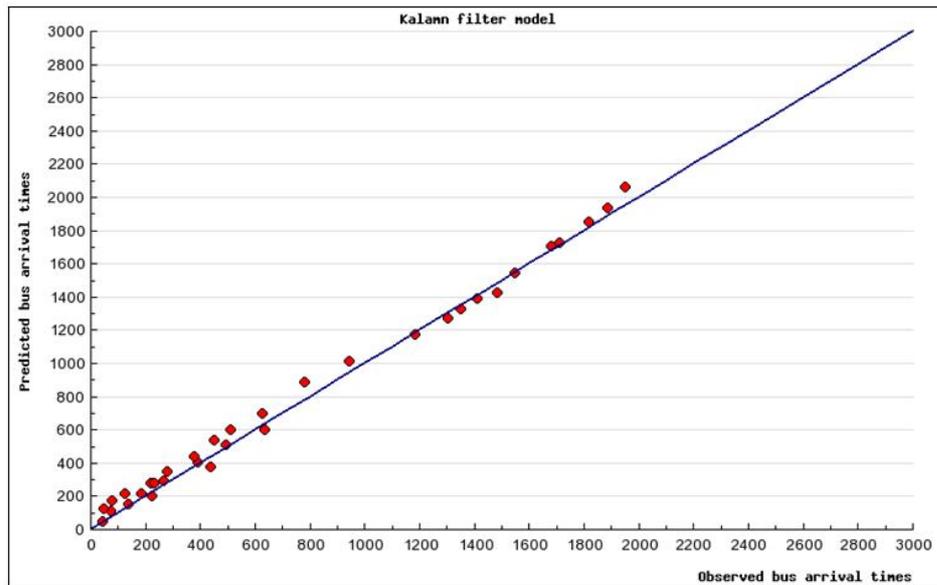


Figure 6-17 Predictability of Kalman filtering model for the second test dataset

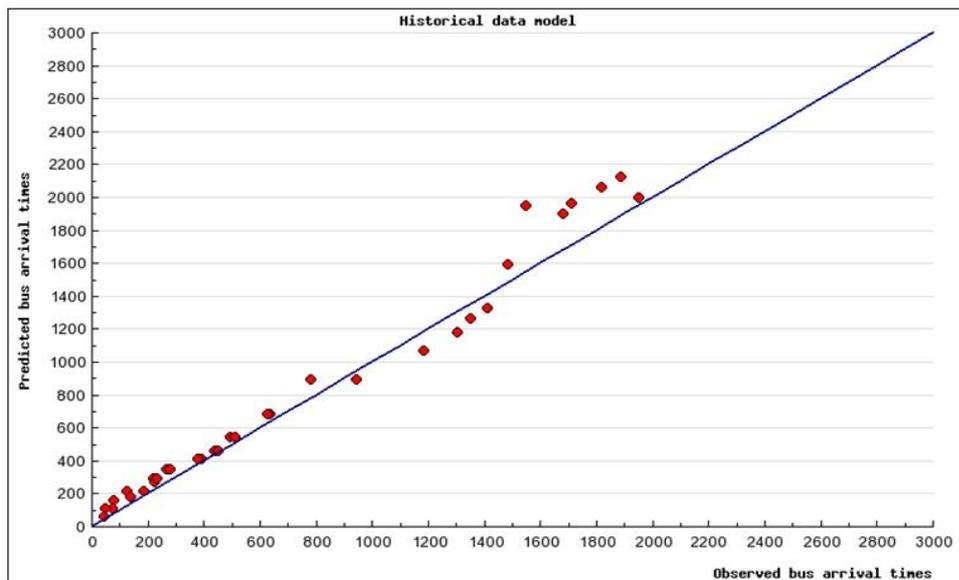


Figure 6-18 Predictability of Historical data model for the second test dataset

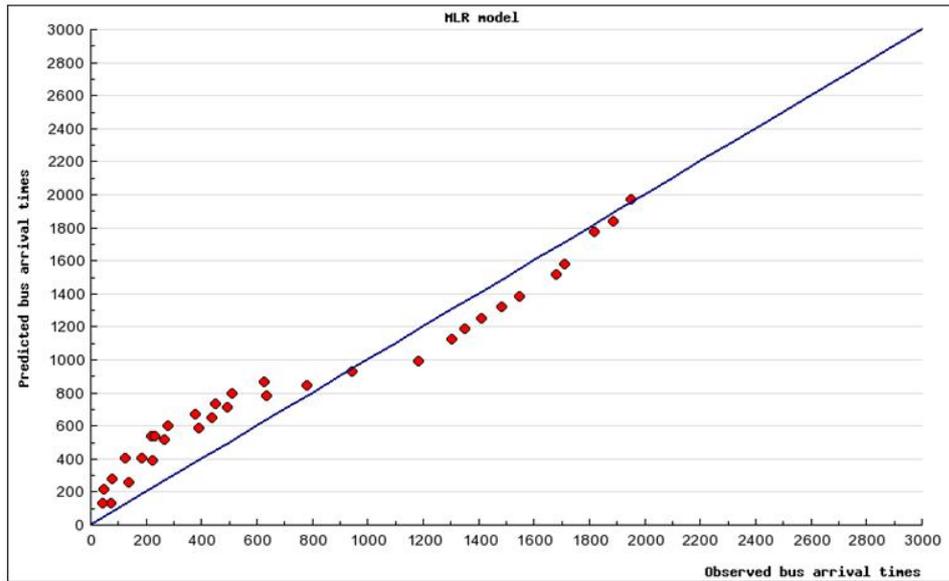


Figure 6-19 Predictability of MLR model for the second test dataset

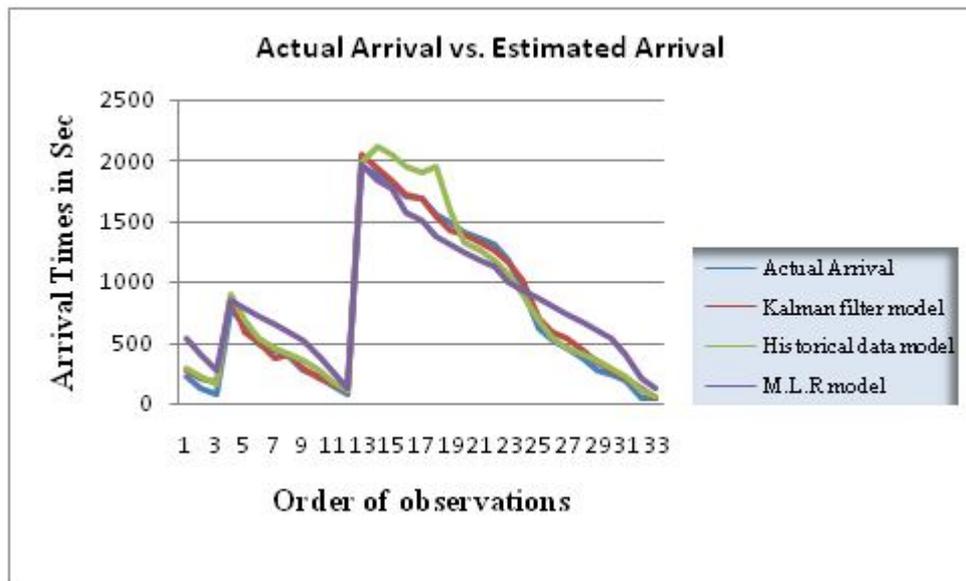


Figure 6-20 Predictability of the three prediction models for the third test dataset

As seen in Figures (6-17), (6-18) and (6-19), the Kalamn filtering model results are more close to the observed values and has less prediction errors. This is clear in Figure 6-20 and the MAPE values shown in Table 6-7.

Table 6-7 MAPE values of three prediction models in seconds for the third test dataset

<b>Model</b>	<b>MAPE</b>
Kalman Filter Model	4.6 %
Historical-data Averaging Model	5.6 %
Multiple Linear Regression Model	10.7 %

### *6.3.10 Overall Performance Evaluation of Prediction Models*

We measured the overall performance of these three prediction models with the results presented in Table (6-8) showing the MAPE values of the overall prediction performance. As we can see from the MAPE values, the Kalman filter model outperformed the other models and the MAPE values for the Kalman filter model were the closest to the observed arrival times. This may be attributed to the ability of the Kalman filter model to update itself based on new data that reflects the changing characteristics of the vehicle operating environment (Shalaby A., Farhan A., 2004). This helps the model to minimize prediction error and produce better predictions. The historical-data based model performed slightly better than the MLR model, as this model performs better when there is a similarity between historical data and real-time data patterns. However, the performance of these three models could be improved with more data.

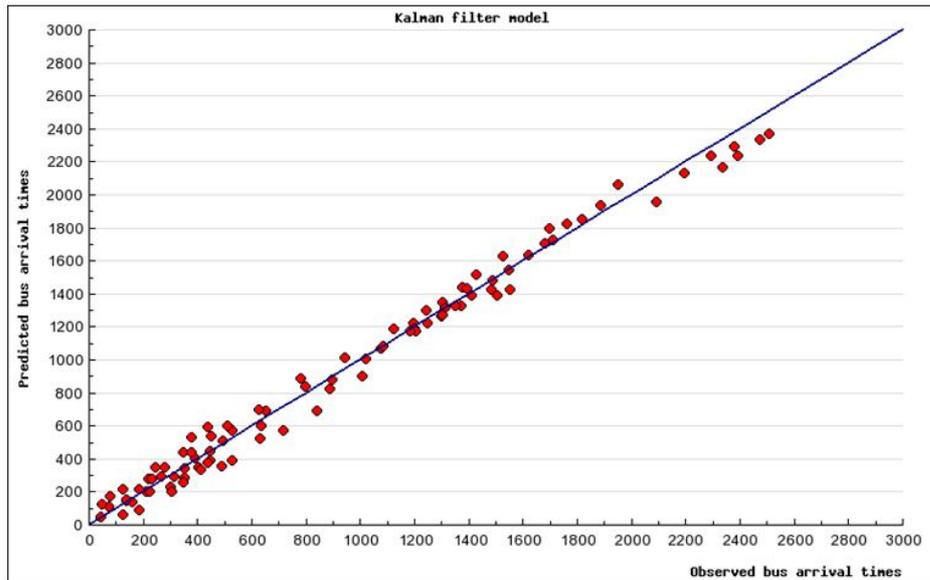


Figure 6-21 Overall predictability of Kalman filtering model

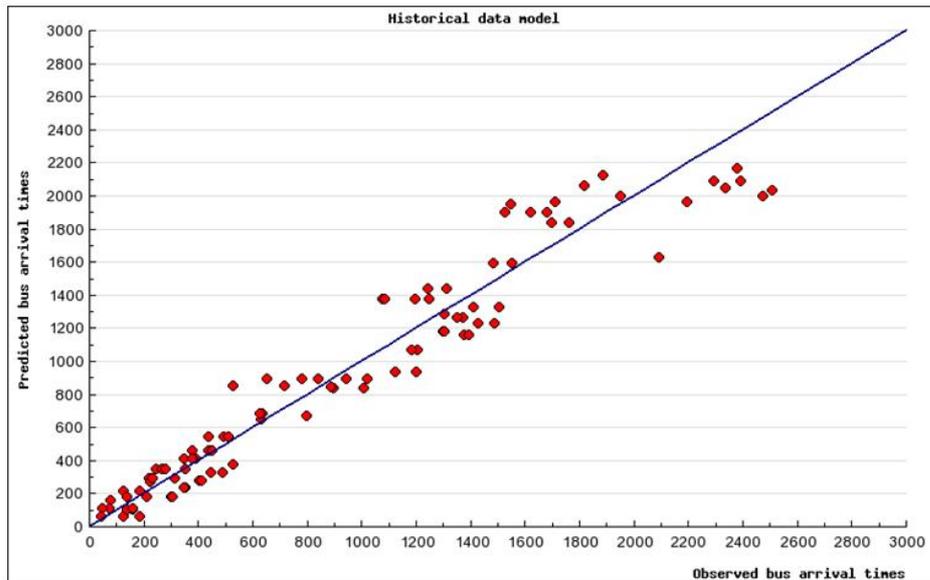


Figure 6-22 Overall predictability of Historical data model

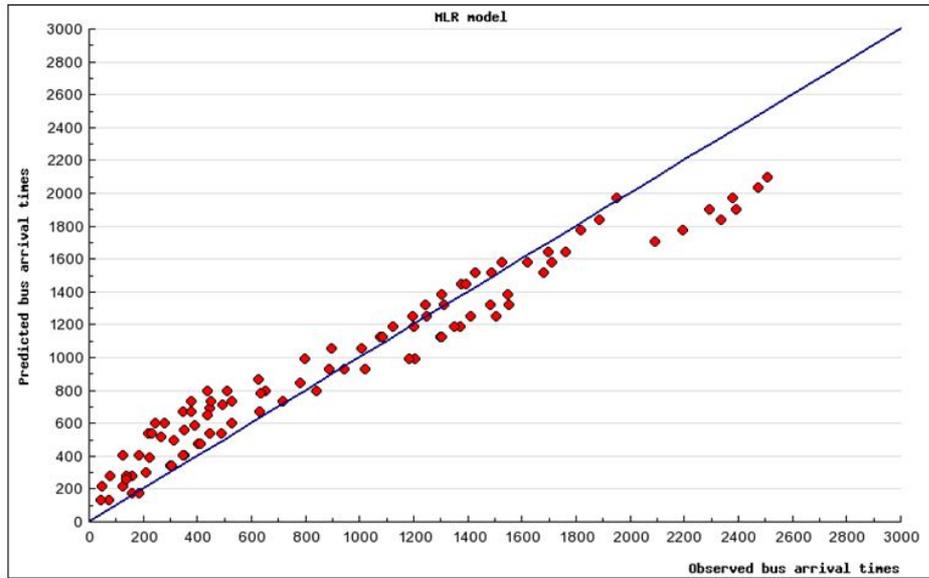


Figure 6-23 Overall predictability of MLR model

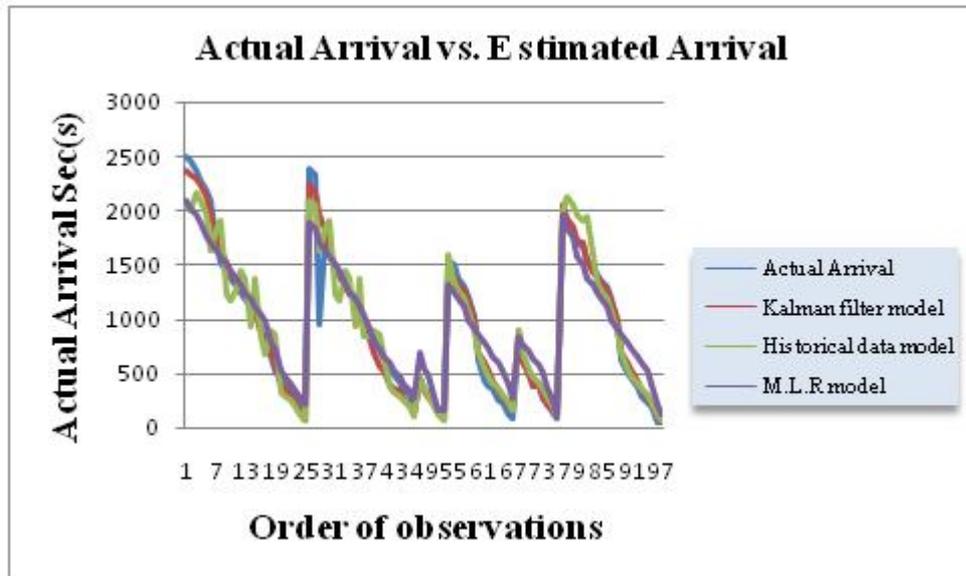


Figure 6-24 Overall predictability of the three prediction models

Table 6-8 MAPE values of overall prediction performance of prediction models

<b>Model</b>	<b>MAPE</b>
Kalman Filter Model	4.4 %
Historical-data Averaging Model	7.2 %
Multiple Linear Regression Model	7.4 %

A histogram was generated using MAPE values calculated for different observed travel times. The results are shown in Figure (6-25). For example, for an observed travel time between 20 and 30 minutes, the Kalman Filtering model can give prediction with less than 4% error. The historical data model gives prediction with 11.5% error and the multiple regression model's prediction can be given with less than 8% error. On the other hand, when the observed travel time becomes larger, the prediction error starts to increase. This could be attributed to the fact that when a bus takes longer to complete a trip, there is a probability that it stops at many stops, especially when passenger demand is high, which increases stop time at these bus stops. The prediction error for shorter travel times was found to be high for the three prediction models, which indicates the high variability in travel time for a short distance. For example, on a short-distance journey, a bus could spend one to two minutes waiting at a traffic light or serving passengers at a bus stop, where the bus may take up to four minutes to cross it. The results show that the overall performance is quite promising: thus, it is possible to provide real-time travel information for system users with minimal prediction errors.

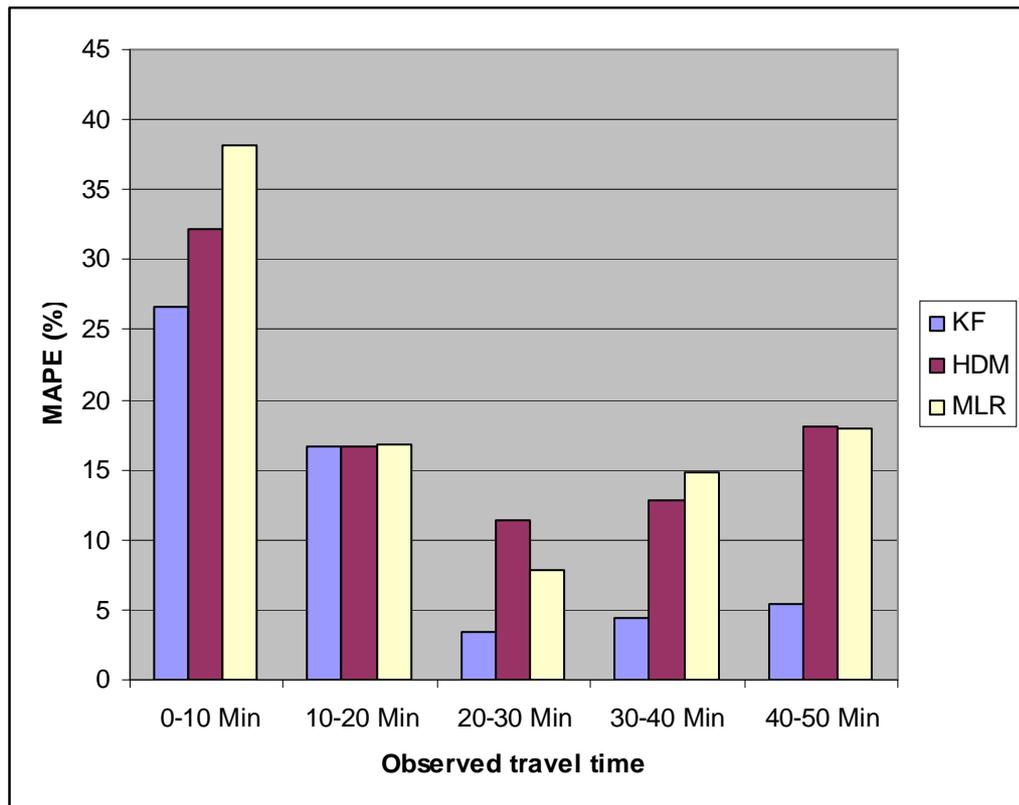


Figure 6-25 Observed travel time vs. MAPE for the three prediction models

It can be seen from the figures that the Kalman filter model results are much closer to the observed data than the other two models. The results summarized in Tables (6-3, 6-5, 6-7 and 6-8) show that the Kalman filter model provides the minimum value for the error measures, pointing to the fact that its performance was the best compared to the other prediction models. This is believed to be due to the ability of the model to capture dynamic changes due to different bus operation characteristics as real-time data continuously updates the Kalman filter parameters as opposed to the historical-data and multiple-regression models which are typically calibrated using historical data and infrequent recalibration of these models. Based on the results shown, the Kalman filter model was chosen to predict bus arrival times in our system.

## ***6.4 Conclusion***

In this chapter we discussed and tackled two types of uncertainty associated with real-time transit services. We provided a new search strategy method to tackle positional uncertainty and optimise the search efficiency in finding the nearest stop to a moving transit vehicle. The new method improves the locating and identification of the nearest stop within the database of stops for the route. The uncertainty associated with real-time bus arrival was tackled by examining three bus arrival prediction models that provide transit users with an estimated time of arrival. Historical data-averaging models work better for transport networks with stable traffic congestion and travel time patterns. However, the drawback of these models is that the accuracy of the results is dependent on the similarity of travelling patterns. The Kalman filtering model was shown to out-perform the historical data model and the multiple linear regression model, proving more accurate predicted arrival times. In the next chapter we will discuss the process of developing, implementing and the overall integration of the various components of our public transport system. This includes some detail on the technologies used to develop this system.

# **Chapter 7 Public Transport Software System Development & Overall Integration**

## ***7.1 Introduction***

The previous three Chapters described the theory and design of tools and techniques for improving public transport information. In this chapter we describe the integration and implementation of the various system components into a comprehensive public transport software system. Our public transport software system comprises various hardware and software technologies such as web applications, vehicle location systems and communication networks. The development of such a system can be achieved through the integration of these available technologies. We will thus describe the design, implementation, and overall integration of the client application for our public transport software system which can track transit vehicles in real-time and provide passengers and operators with up-to-date transit information. This will include a comprehensive description of the functionalities of system components.

## ***7.2 System Overview***

The system's users can be broadly classified into three major groups: passengers, operators, and regulators. The public transport software system is a software application proposed to provide transit users with real-time information through innovative and efficient tools. Multiple standard web interfaces were developed to prompt greater access to transit information and allow passengers to obtain information when they need it. These web interfaces allow users to search and navigate transit information. Results are visualised on a standard map or in tabular format. In addition to the standard web interface, internet-enabled smart phone interfaces were developed to enable transit users to easily access information. The mobile-based applications utilise phone's built-in sensors such as GPS and digital compass to acquire information in an easy and intelligent way.

The system offers transit operators tools to track, monitor and evaluate vehicle fleet performance. These tools help transit operators visualise vehicle behaviour and detect any symptoms of bad service at an early stage. In order to improve the transit service, the system collects transit data and builds up an archive that can be analysed and mined for information showing transit vehicle behaviour over time. Full archiving of transit data gives the potential for calculating metrics and summaries of system reliability and Quality of Service (QoS). This helps operators to report QoS to regulators for the purpose of verifying their license conditions and for the award of public subsidies.

### *7.2.1 Technology Overview*

Currently, there are several tracking solutions in different forms. Some operate in client-server architecture while some others work in standalone mode. While a client-server system is a better solution when considering cost, a standalone solution will give better speed of response. There are other trade-offs such as upgrading and updating of geo-information, which is convenient in a client-server architecture as the upgrade can be done at the tracking server. In a standalone architecture, geo-information coming from tracking units (GPS/GPRS) needs to be upgraded in each instance of the application. Since we are interested in developing a low-cost system, we first adopted a client server architecture.

Figure (7-1) shows the system block diagram, highlighting the interaction between the different components of the system. As we can see from Figure (7-1), all of the component technologies have been designed to interact with the database the same way using HTTP whether they are updating the database or accessing the stored information. The GPS/GPRS unit sends vehicle information to the server every 45 seconds. This time is sufficient to send data and long enough to make a difference in the location of the vehicle. It is possible to change or adapt it for a different configuration.

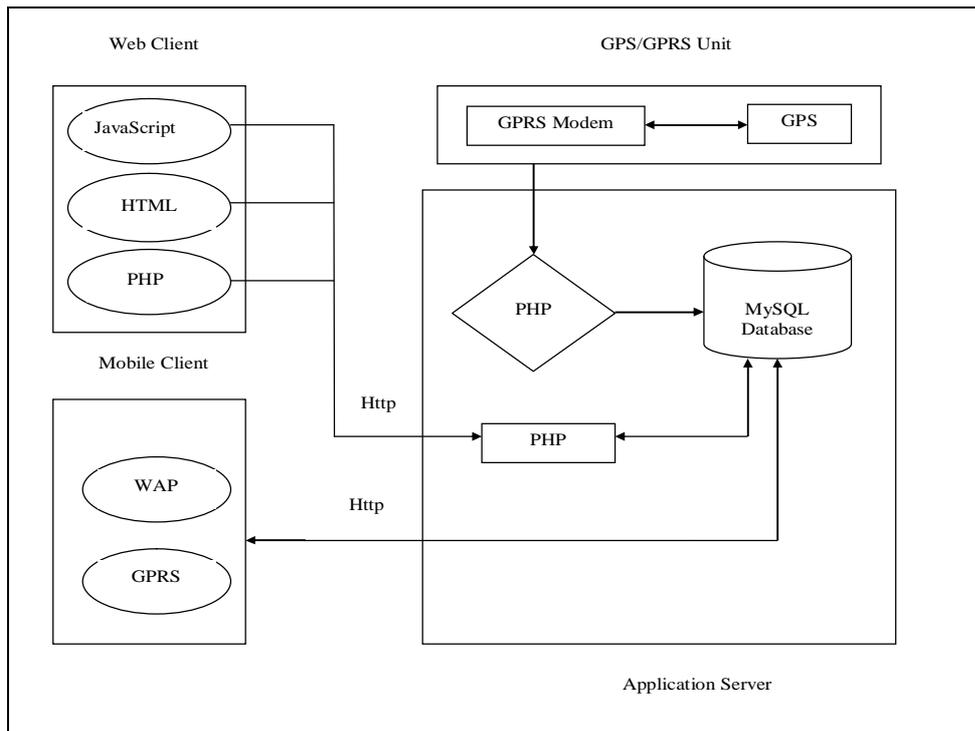


Figure 7-1 System block diagram

As mentioned earlier, the transit server is designed in two stages: The first being the handling and storage of the vehicle location in a database, while the second being the provision of this data to client/user requests. PHP (PHP, 2012) is used as the server side scripting language. A PHP script receives the vehicle information and determines the nearest bus stop. This involves a database lookup to find stop information in the route and calculating the distance between each of these stops and the vehicle. This is then used to produce an accurate arrival time for the vehicle at the approaching stop. All updates on the client side are done through (HTTP).

### 7.2.2 System Architecture

The public transport software system addresses the design constraints and the trade-offs to provide a better solution. The architecture is a client-server architecture where the web browser is the client and the server is a web server. An open source Microsoft Bing map is selected as the map server in order to make the solution the most cost effective. GPRS is chosen as the main method of communication between the tracking units and the server. GPRS, is a 2.5G mobile technology which is ubiquitously available. It is also ideally suitable for data transfer over an always on-

line connection between a central location and mobile devices. Figure (7-2) illustrates the architecture of our real-time bus tracking system.

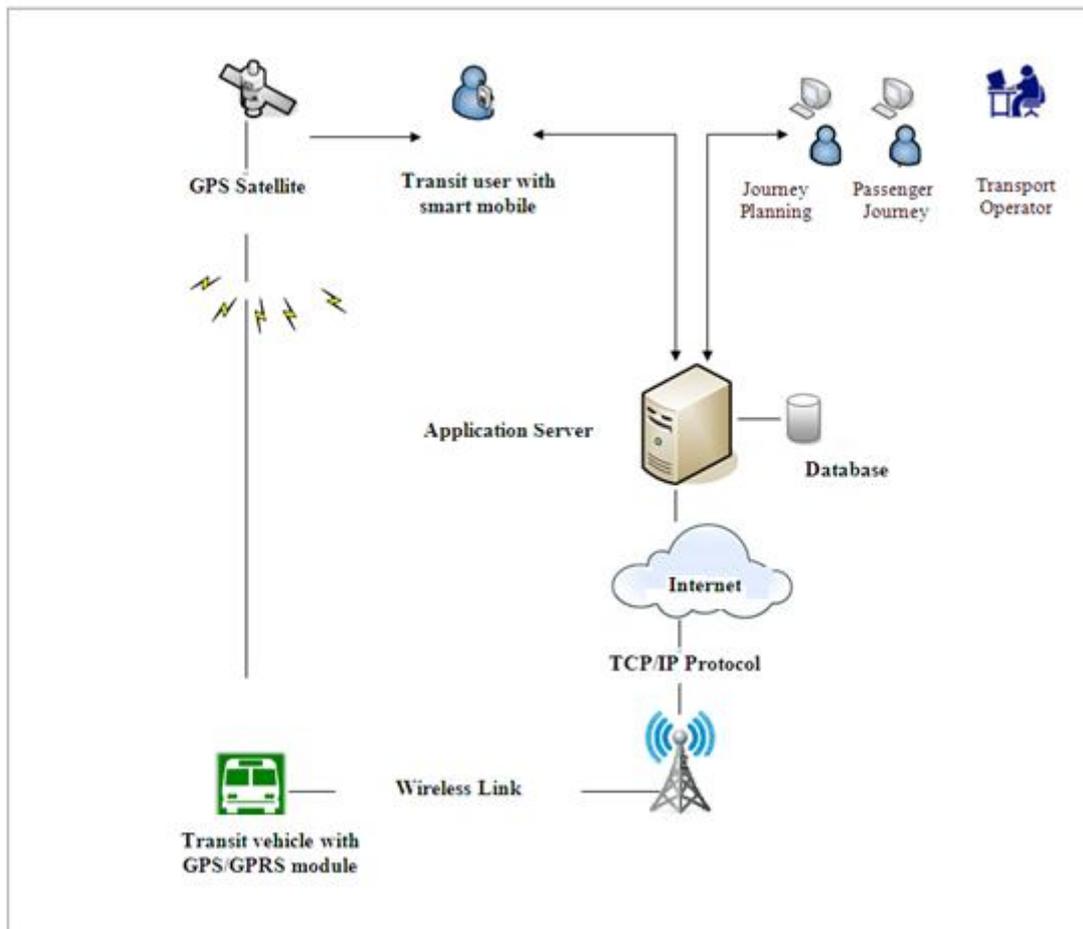


Figure 7-2 System architecture of real-time bus tracking system

As we can see in Figure (7-2), transit vehicle location is determined using GPS, while the transmission mechanism, using a low-cost GPRS wireless data communication system, is provided by cell phone operators through the nearby cell tower. A direct connection with the application server is performed using a TCP/IP connection. The remote server receives vehicle information and stores this information in the database. The application server uses PHP as its scripting language and MySQL (MySQL, 2012) as the database. The data is analyzed and stored, then made available to the end-users through a web-based or mobile-based interface.

The actual data flow in the real-time bus tracking system is shown in Figure (7-3). The raw data location/time is streamed from the GPS-based AVL system which is installed in transit vehicles. Each bus is assigned with the route it is operating on and is usually fixed and predefined by the operators. Arrival of the vehicle at a bus stop is detected when the vehicle is at a close distance to the bus stop. Once real-time transit information, including estimated arrival times, is available various forms of interfaces can be used to deliver this information.

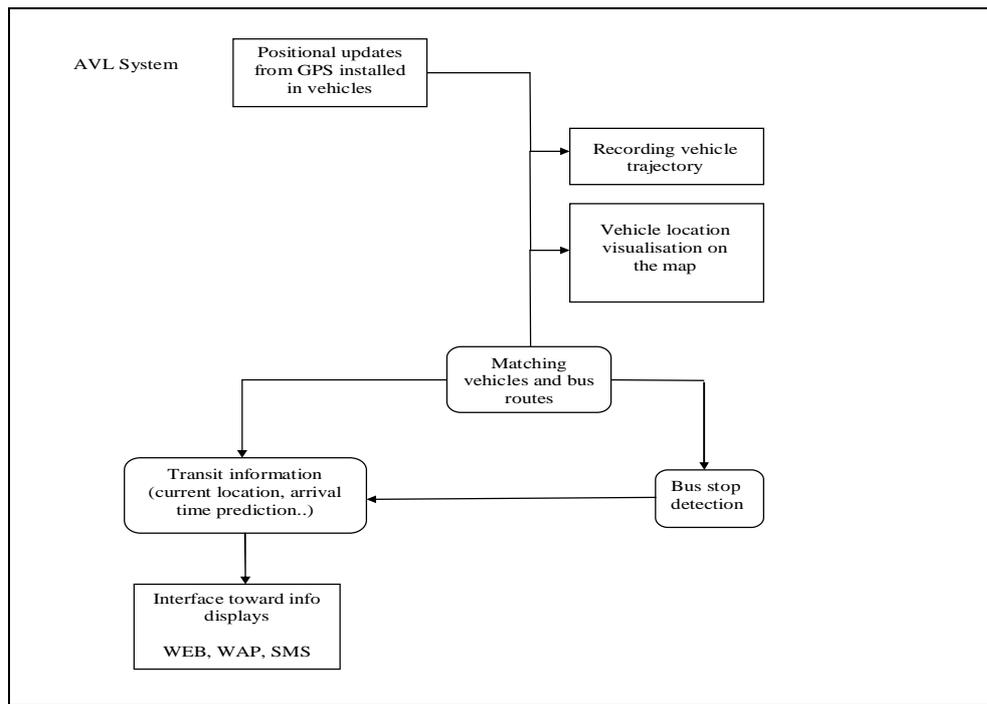


Figure 7-3 Data flow in real-time bus tracking system

Our public transport software system is an application that runs on any standard computer with internet connectivity through a web browser. This application is interactive; users can quickly navigate to a transit system and extract the desired information. As seen in Figure (7-4), our public transport system needs to request information from the server through a Http Request. After a request is received from a client, the server will give a reply to the users.

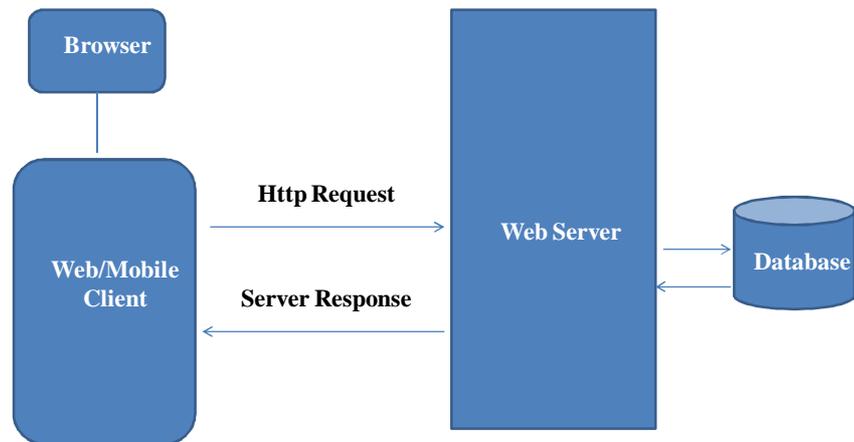


Figure 7-4 User interaction with the transport system

In addition to tracking transit vehicles in real-time, the transport system provides a better estimation of bus arrival times to bus stops along their routes. Thus, the system application consists of two main components: tracking and prediction elements. As seen in Figure (7-5).

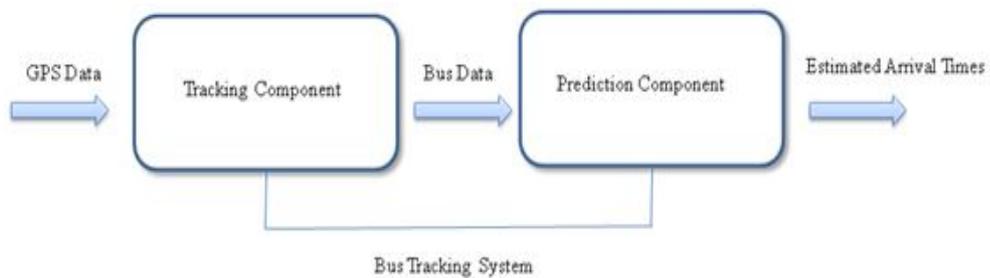


Figure 7-5 Tracking and predicting components of real-time bus tracking system

## ***7.3 System Design***

This section describes the detailed hardware and software design of our public transport software system as well as the functionalities of each component. Section (7.3.1) describes GPS positioning and GPRS as data transmission services. This integrated technology enables us to relay data from the field to a central server. In Section (7.3.2), we describe the tracking server where transit data is stored and analysed. We also discuss software design in Sections (7.3.3) and (7.3.4). This includes descriptions of the structure of the database and the tables created to store transit data.

### ***7.3.1 GPS/GPRS Integrated Unit***

To design a comprehensive cost-effective application for tracking and monitoring transit vehicles in real-time, low-cost hardware components need to be considered. These components include GPS positioning systems and a low-price wireless communication network for transmitting vehicle data to the remote server and storing the collected data. A GPS/GPRS integrated sensor unit is installed in each transit vehicle. This in-vehicle unit collects transit vehicle data via GPS, formats this information into a system-specific packet format and sends it to the server via GPRS. If GPRS is unavailable at any time, time-stamp data packets are stored in a temporary storage unit to be uploaded when GPRS becomes available again. Thus, the movement information of transit vehicles is not lost even in the event of a communication failure. Figure (7-6) shows an image of the GPS/GPRS integrated unit that was used.



Figure 7-6 GPS/GPRS Integrated unit

As we can see in Figure (7-7) to communicate with the remote server and store transit data, the in-vehicle unit follows many steps. The workflow of the system is as follows: after the in-vehicle unit is turned on, it automatically initialises the network. Then it gets the GPS data with its unique International Mobile Equipment Identity (IMEI) number. It then tries to connect with the GPRS. If this fails due to GPRS unavailability, the unit logs the data in non-volatile memory and waits for a certain fixed time period. After that, it tries to connect to the GPRS again. After establishing the GPRS connection, it tries to connect to the service provider's server using the HTTP protocol. After a successful connection, the GPS data with IMEI number is sent to the server as a string. Then, after a certain time period, it checks the availability of GPRS and connects to the HTTP server. The new current location of the in-vehicle unit is now sent. In this way, the device communicates with the remote server and sends the location repeatedly.

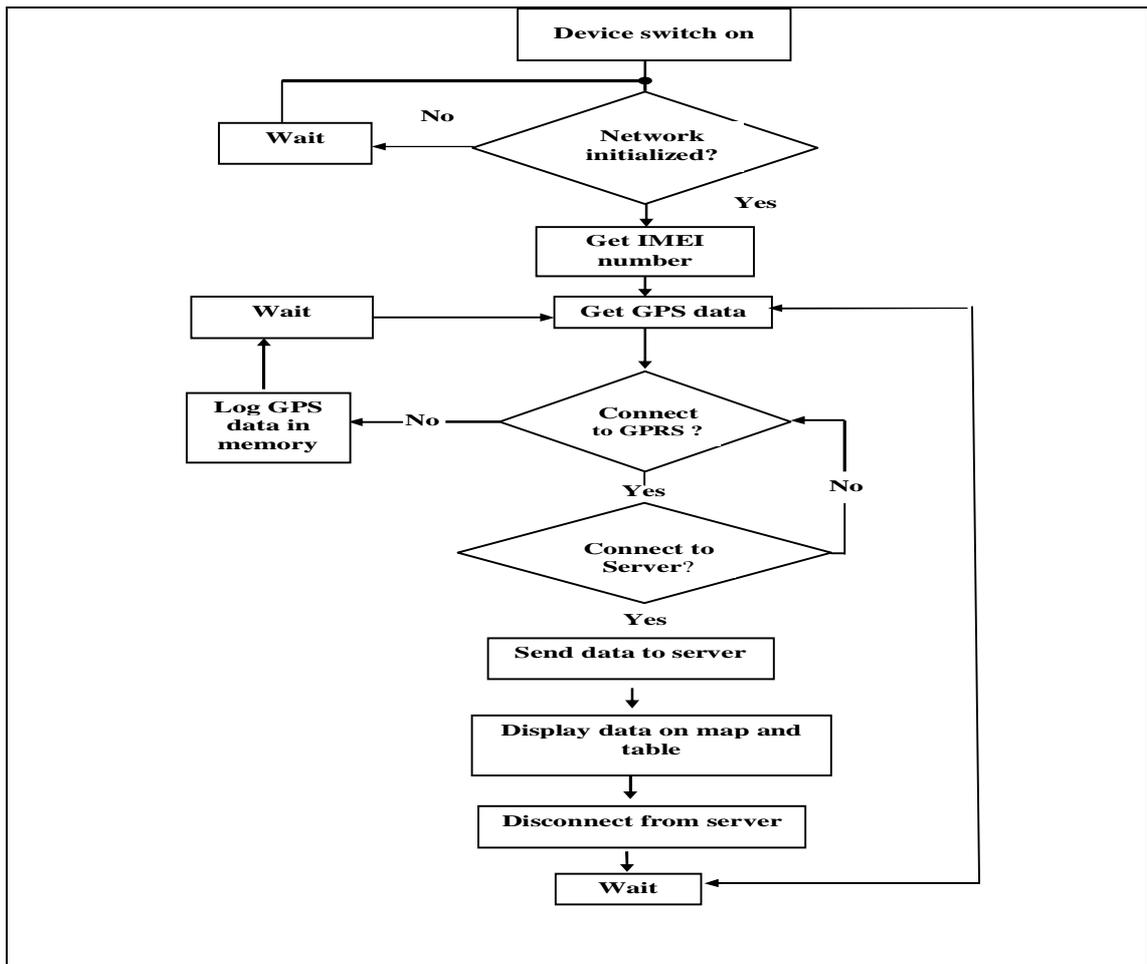


Figure 7-7 The workflow of the in-vehicle unit

### 7.3.2 Tracking Server

Once the GPS Tracking Module is connected to the GPRS network, it transmits transit vehicle information to the remote tracking server. The remote tracking server maintains all transit vehicle data received from in-vehicle units in a MySQL database. As we can see in Figure (7-8), the tracking server has two functions: to receive the information and to store this information in a database.

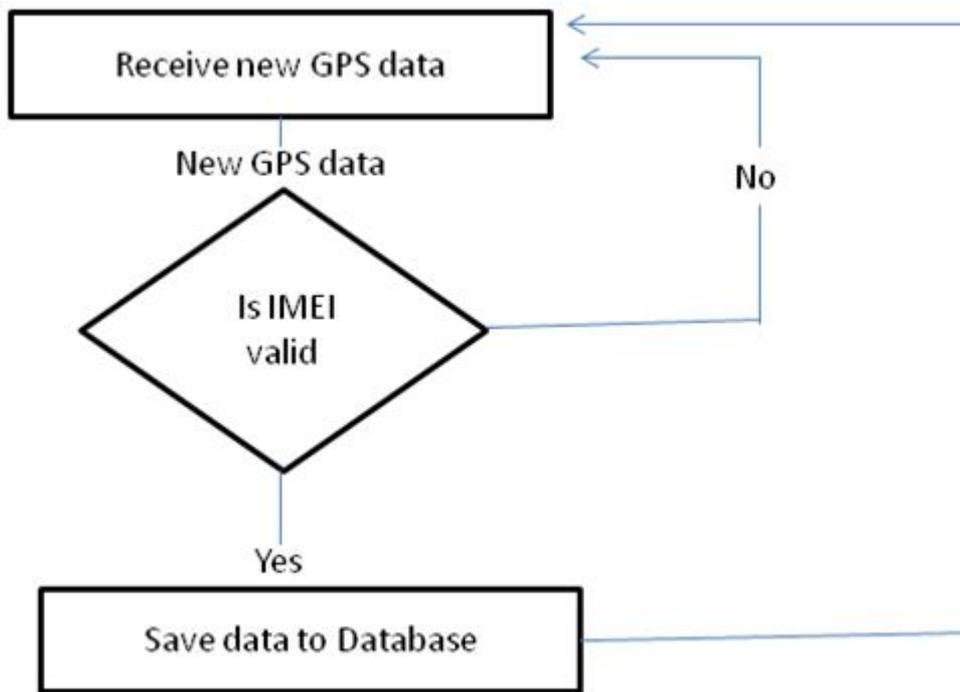


Figure 7-8 Server side flow diagram

The receiving function opens a non-blocking socket to receive data from multiple GPS Tracking Modules simultaneously. The storing function formats the receiving data into the database, which is designed to provide a real-time query response for real-time tracks. The receiving data is integrated with map, route and schedule data, as well as previous real-time updates. This integration uses algorithms to determine whether the bus is in or out of service, the direction of service, and therefore what stop the bus is going to make and the adherence status.

### 7.3.3 Software Design

The main software components of the public transport software system are socket communication software, the web server, and the map server. The socket communication software is the central server component that communicates with the tracking units. It establishes TCP/IP socket connections with the hardware units. It is capable of communicating with multiple client units using multiple threads. When a GPS/GPRS unit connects, the server will authenticate and acknowledge the unit. Then, the server will proceed to receive the information from the tracking unit and will store them in the database. The web application will retrieve the data from the

database server and do preprocessing for further operations as requested. The web application also includes management tools for the system.

#### *7.3.4 Database Design*

Data used in the real-time bus tracking system is conceptually separated into two types: temporal and non-temporal data. The list of transit vehicles, bus routes, timetable data and stop locations are all treated as static data. The daily schedules are the temporal data, which can be fetched anew every day. Figure (7-9) illustrates the relational database design and table structure. Within the tracking system, the database cannot be accessed directly by the users: rather, user queries are answered by web services, which return the response to the client. The database, as shown in Figure (7-9), is designed to store the static data of the transit system as well as all received information from transit vehicles. Information to be stored in the database is:

- Daily schedule information
- Information about vehicles
- Information about bus routes
- Information about bus stops
- Information about bus schedules

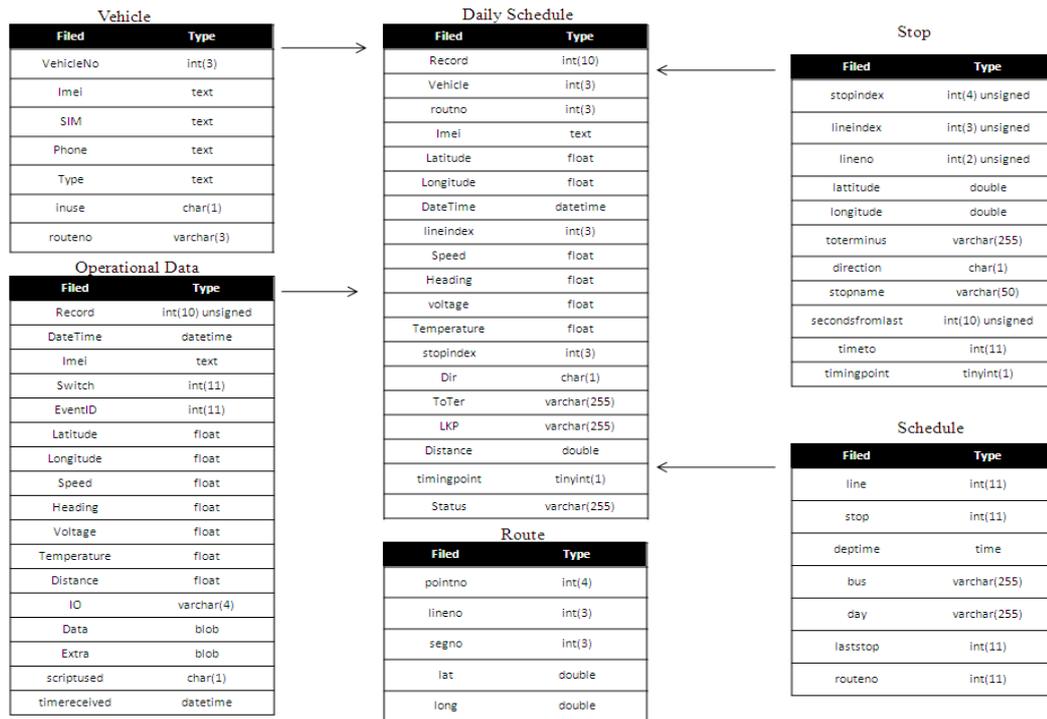


Figure 7-9 Relational database and table structure

The daily schedule table stores all information about transit vehicles. Data in this table is fetched anew every day. Information such as vehicle number, current location, direction, destination and adherence to the schedule, with other details, are stored in the daily schedule table. The vehicle table stores information such as vehicle type, vehicle number, route number and in-vehicles unit modem details, such as the in-vehicle unit's unique International Mobile Equipment Identity (IMEI) number, in-use status, and other details.

The Route table maintains an ordered list of points and their coordinates along the bus route. The bus route consists of segments, so every point has a segment number, and these points together form the bus route. These points allow the route to be drawn on a map by using the ordered list of points from the Route table. The Bus stops table stores the latitude, longitude, stop name, stop index and other details of bus stops. The Bus schedule table stores data about arrival and departure times; it includes line number, bus stop number, arrival and departure times and route number. In addition to transit information, the bus tracking system keeps information about users in the Users table; this information includes the username and password.

### *7.3.5 Use of Geo-Spatial Data*

Every 45 seconds, the central server receives bus AVL data which is continuously transmitted by each in-vehicle's unit using the GPRS data communication network. The tracking module, which is the core of our public transport software system, starts to process the incoming data. The tracking component uses up-to-date GPS data to classify and map the buses on a real-time Bing map which will be accessible through the web. Buses are classified on the basis of being "in-service" or "out-of-service" (if the recent location does not match with a known route). As we can see in Figure 7-10, the system uses GPS and timestamp data to classify transit vehicles. This is done by comparing the vehicle timestamp with the current time as well as the location coordinates of the vehicle compared with the coordinates of the bus route and a set of predefined locations such as the bus depot. Once transit vehicles are classified, the recent location is depicted on the map. If the vehicle is deemed to be "in-service" its current location in terms of the nearest bus and schedule information are extracted as prediction parameters. The prediction component uses these real-time vehicle data to produce arrival time predictions. Figure (7-10) illustrates the vehicle classification and arrival time prediction processes.

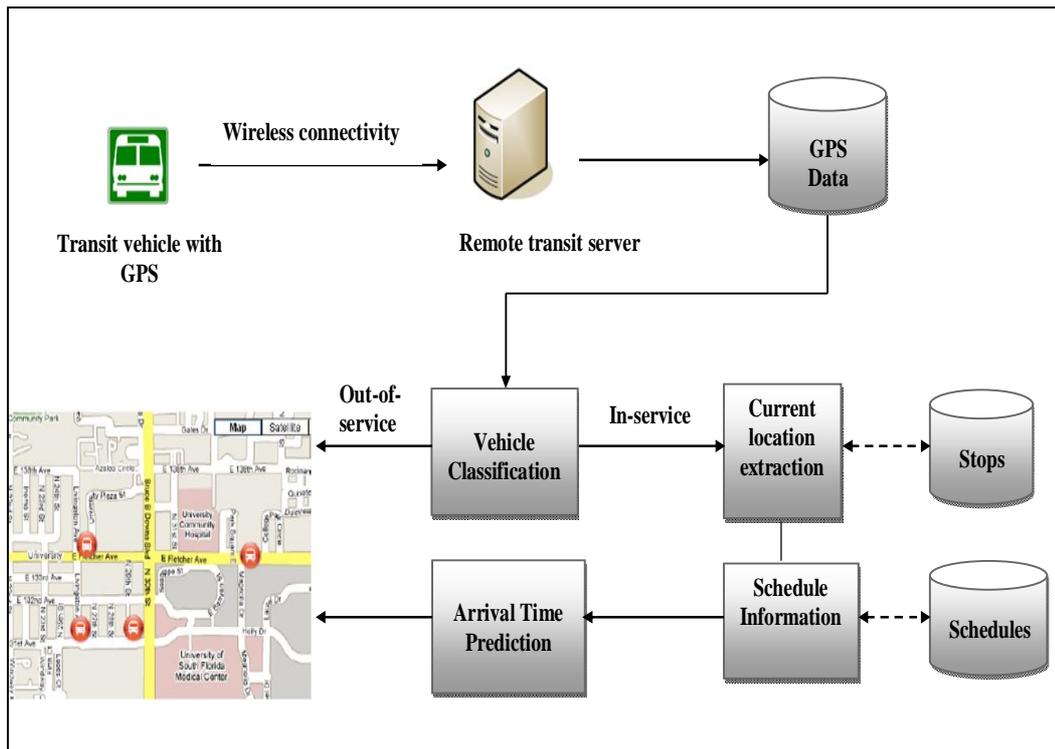


Figure 7-10 Vehicle classification and arrival time prediction processes

### 7.3.6 System Interfaces and Software Tools Design

As described earlier, the tracking server maintains all information in a database. To display this information to the end user and transit operator in an easy and accessible way through computer or mobile devices, computer techniques are required. Interface design concerns are related to the presentation of the data to the end-user. Better and more intuitive access to transit information empowers transit users, creates a better overall experience and improves the public perception of transit systems. The user interface should enable the complete navigation of the transit region map via a variety of interactive gestures and tools. Features including arrival time prediction information, alarm notification of a selectable bus stops and searching for a particular bus stop, transit vehicle or point of interest. These are all valuable tools which allow transit users to make better travel options. As shown in Figure (5-3), the transit system has a public interface that can display and update vehicle locations in Microsoft Bing maps.

A list of bus stops is available to enable users to see the next buses coming to the selected stop. This feature enables users to receive the expected time of arrival of the next upcoming bus(s) to this stop. The system's public interface offers the transit user the ability to display a particular bus stop or transit vehicle on the map, as the location of the bus stop or the current vehicle location is subsequently shown on the map with the detailed information. Transit users can use the 'search on map' utility to search for a particular point of interest and show nearby bus stops with associated transit information. Through the user interface, transit users can access timetable information to search for arrival/departure information using the route number or bus stop number. To see the real-time progress of buses, a graphical view has been designed and is accessible through the user interface. The trip planner or trip advisor interface is available for users to search the transit system for pre-trip information. This tool integrates real-time transit information with pedestrian navigation systems to provide transit users with door-to-door journey planning information utilizing real-time transit information instead of static timetables.

#### ***7.4 Web Services for Public Transport Software Systems***

Real-time tracking is the major part of the transit vehicle tracking system. This aspect enables users and operators to view the live position of any transit vehicle on a map. AJAX (Asynchronous JavaScript and XML) is a set of different technologies that work together to create powerful web applications (Asleson R. and Schutta, N. T. 2005). AJAX is a style of web application development that uses a mix of modern web technologies to provide a more interactive user experience (Ahmet S., et al, 2006). AJAX is not a technology. It is an approach to web applications that includes a couple of technologies. These are JavaScript, HTML, Cascading Style Sheet (CSS), Document Object Model (DOM), XML and XSLT, and XMLHttpRequest as messaging protocol.

AJAX applications give certain benefits over desktop applications because they are independent of a specific operating system, virtual machine, browser, plug-ins, or

external programs, these features have attracted strong interest among web application developers and is now very popular (Zepeda J.S. and Chapa,S.V., 2007).

These applications only need a modern browser with access to the Internet on the client side and offer easier support, faster response and rich user interaction. Most AJAX applications have different layers working together: one layer is the user interface, and the second is JavaScript code with an AJAX engine. The user interface includes Hypertext Markup Language (HTML), Extensible Hypertext Markup Language (XHTML), Cascading Style Sheets (CSS) and Dynamic Object Models (DOM). HTML formats the content of the web page using tags. CSS offers the separation of content and presentation on the page through style documents. DOM offers a means of dynamic access and updates the content, structure, style and elements of the web page. When the web page is loaded on the client side, if the application does not require an external request, an AJAX EventListener sends data to functions previously programmed to update the content, presentation, or structure of a web page's content through the DOM and CSS.

When the application requires data from the server, a request object is created in a different way depending on the browser. Internet Explorer uses a special class called XMLHttpRequest, while Firefox and Safari use the XMLHttpRequest object. These classes have different constructors but their behaviour is the same. Once the request object is created, a connection with the remote server can be made and a request can be sent in a synchronised way through the HTTP or HTTPS protocol. The HTTP request is processed on the server-side and its progress indicator changes through the readystate property (w3schools, 2012). When the request is processed, the database returns new data to the Web application, where the data gets transformed into a specific format (XML, HTML, plain text, etc). The web application then sends the response back to the client-side, where JavaScript functions parse the content and the update functions update the content, presentation, or structure of the web page content through the DOM and CSS. Figure (7-11) shows the AJAX Web Application model.

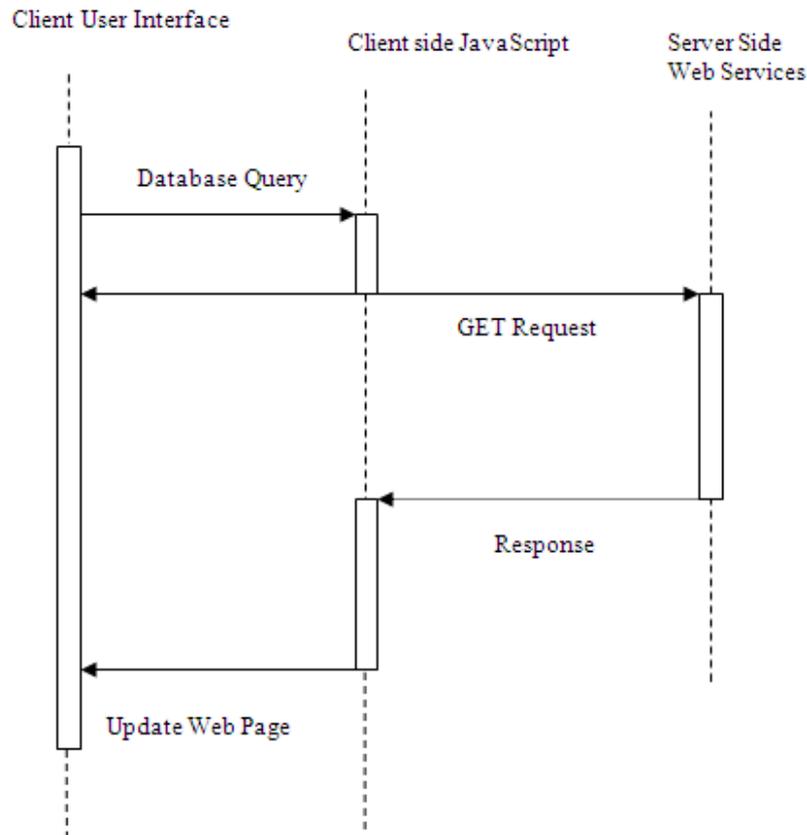


Figure 7-11 AJAX Web Application model

Throughout the real-time bus tracking system, users will make requests for the information they want to see. By answering their requests asynchronously, the system interfaces do not refresh themselves like classic web pages. Rather, the map and interface continue to be interactive and work correctly, with the request response resulting in new data being displayed as soon as possible. In our system, each web service resides in its own unique URL to differentiate and partition the services. All requests are made through HTTP requests facilitating asynchronous JavaScript (Batra, S., 2006).

In our developed bus tracking system, a PHP script called *UpdateMap&Table.php* contains client user interface code with a JavaScript function used to fetch new transit vehicle data from the tracking server. On the server-side a script called *getthelastnformation.php* processes the request and sends the response to update the map and table in the user interface. This is done at fixed intervals to update the map

and table without reloading the whole web page repeatedly. Figure (7-12) shows the real-time bus tracking system interaction.

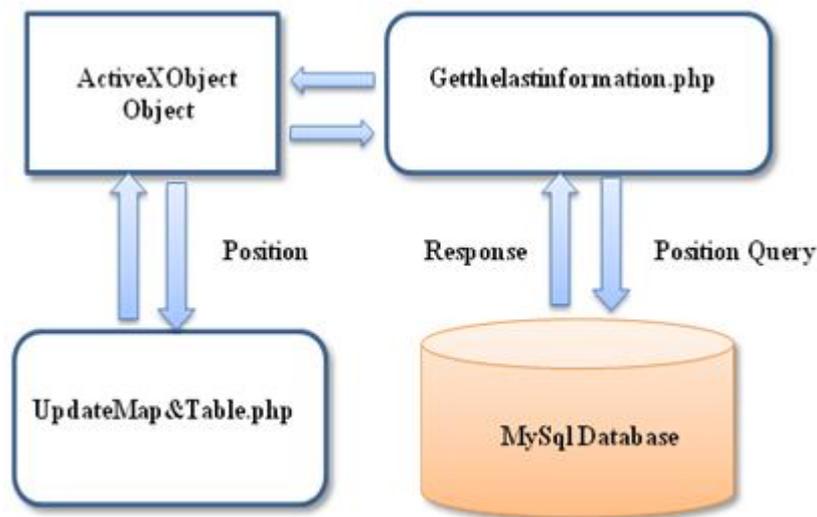


Figure 7-12 Real-time bus tracking system interaction

## 7.5 System Implementation

The system required that many different parts work together to accomplish their tasks. Our system uses real-time location data for buses in Blackpool transport (Great Britain) to develop web interaction interfaces and develop the bus arrival time algorithms. The data that is stored in the tracking server is used to map the transit vehicles on a real-time map-based web interface. The system provides users/passengers with a variety of interface operations and the underlying implementation is diverse as a result. On the server side we used PHP as a scripting language as it works very well with database management systems, such as the MySQL database. For user and transit operator interfaces, and to allow tracking of transit vehicles on a map, the transit region had to be mapped and embedded in the project webpage. The Bing Maps API from Microsoft was used. Bing Maps code is written in Java Script and XML. On the client-side we used HTML, XML, JavaScript and PHP. The system is composed of a number of modules each providing specific functionality. Client-side AJAX applications are written in JavaScript. For the

mobile application we used Java as it is a platform independent and object orientated programming language (Ronald T., et al, 2009). Platform independent programming languages don't rely on any particular features of a computer's architecture which allows it to be very portable.

The real-time bus tracking application software is developed based on best practice expressed for source code quality including readability, maintainability and low complexity. The software was written in such a way that another individual can easily understand and update it if necessary. The software is broken down into individual scripts, each focusing on a particular and singular task, so as to have the least complexity possible. A copy of the PHP and Javascripts scripts are included in Appendix A.

## ***7.6 System Hardware and Software Testing***

A real-time bus tracking system can be considered as an assembly of technologies and equipment that allows location determination, display and control of the position and movement of a transit vehicle with the ability for performance evaluation and transit information provision. As we can see, Figure (7-13) illustrates the overall system integration. The hardware component of the real-time bus tracking system includes a positioning facility and transmission mechanism to transmit vehicle information to a central tracking server with storage facility. The software components of the real-time bus tracking system includes a control program, databases, and interfaces.

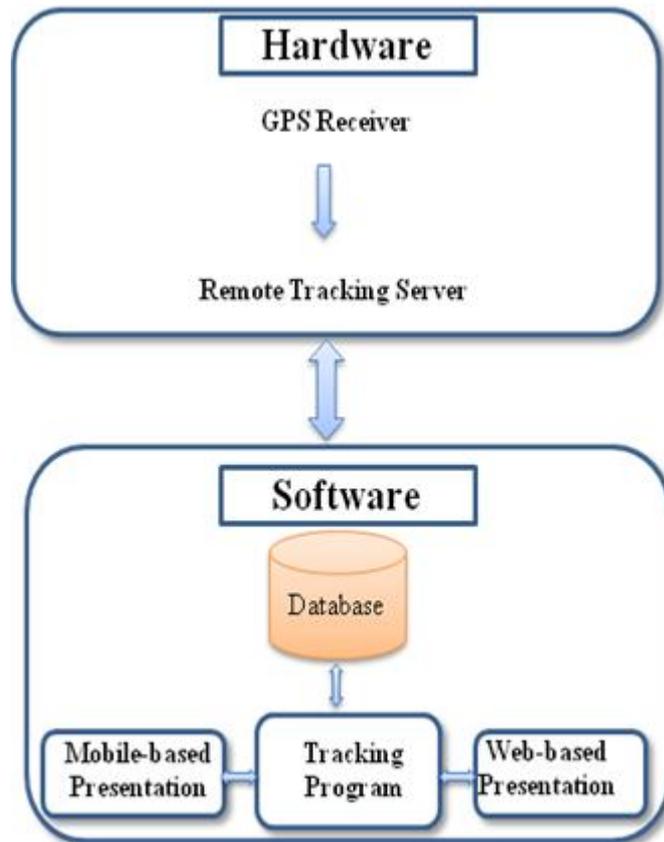


Figure 7-13 Real-time bus tracking system overall integration

The system design needs to be verified by testing after integration of all components to determine whether the system meets its requirements and discover any design errors or system defects. We conducted a test for the hardware and software components of the system. The hardware part, which includes the GPS/GPRS integrated unit, is installed and fixed into the cabin of a transit vehicle. The GPS/GPRS antenna is connected and the unit is configured to transmit vehicle information. When the GPS/GPRS unit is powered on it starts to extract/process information and sends it to the remote server. In order to test the remote server, a desktop computer was configured to act as a remote server. An Apache server (Apache Server, 2012) was running and a MySQL DBMS was installed on the desktop machine. A GPS COM was connected to the COM port of the desktop machine and the communication software opened the communication port and configured the server module. After successful configuration it sent an information request to the GPS/GPRS unit, received information sent by GPS/GPRS unit and, finally stored it in the database. We then tested the software components of the

system which includes the coding scripts and modules. This test showed that the modules work efficiently and successfully. Software system testing includes checking for the purposes of quality assurance, verification and validation. We first conducted a test of the software system in terms of the individual components and tools provided. We ran those scripts individually to make sure they are working perfectly and producing the required results. Then we conducted another test of the overall system. After integrating all the system components, the system was tested and successful working of entire system was observed. The real-time tracking system read the information from the database and displayed it in close to real-time performance.

### ***7.7 Usability Test (System Evaluation)***

The usability test and evaluation process of the public transport software system interaction can give specific insights to where the system is working and where it needs improvement. There are a variety of strategies that can be used to assess and evaluate the system, such as a large-scale survey (B. Ferris., et al, 2010). For this research, a group of 18 participants that were postgraduates students who are regular bus users volunteered for the usability tests of the software prototype. These participants had a good knowledge of analysing data and evaluating results. They were asked to use the public transport software system user interface. Before starting the evaluation test, the system and its uses were briefly explained. During the test, every user was continuously observed and evaluated to determine how good they were at operating the system. After the testing session, questionnaires were given to the participants for their feedback.

#### ***7.7.1 User Tests***

Participants were asked to use the public transport software system user interface to perform the following tasks:

- Interact with the transit system to gain arrival times information for bus stop 62
- Allocate and track a particular bus on the transit map.
- Obtain timetable information for a bus route.
- Use the Trip Planner service to plan a bus trip.

### 7.7.2 Test Results

The following tables and graph show the results obtained by summarizing the feedback from the user questionnaires after using the public transport software system. Each test participant rated the system on a Level of Satisfaction (LoS) from 0 to 100.

System performance:

Table 7-1 User feedback on system performance

LoS	No. of Participants
0-40 %	0
45-55 %	0
60-70 %	3
75-85 %	7
90-100 %	8

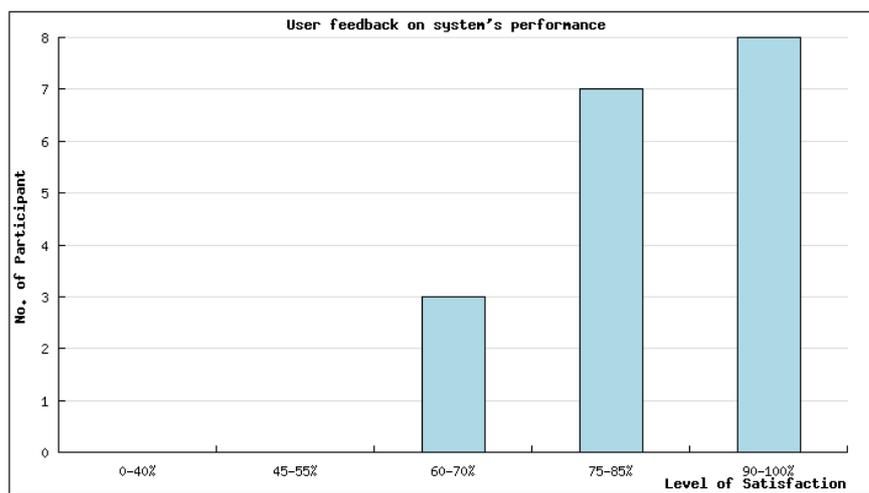


Figure 7-14 Feedback from the participants for the system performance

System tools and interactivity:

Table 7-2 User feedback on system tools and interactivity

LoS	No of Participants
0-40 %	0
45-55 %	0
60-70 %	2
75-85 %	7
90-100 %	9

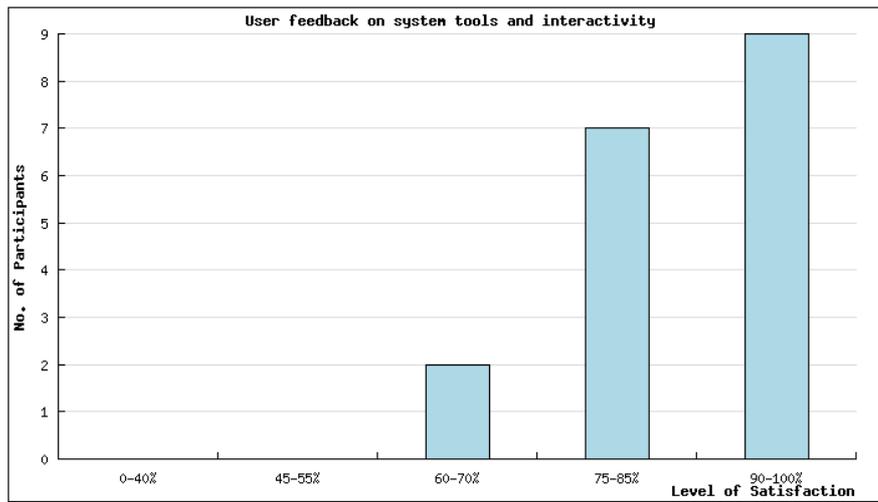


Figure 7-15 Feedback from the participants for the system's tools and interactivity

System presentation and user interface:

Table 7-3 User feedback on system presentation and user interface

LoS	No of Participants
0-40 %	0
45-55 %	0
60-70 %	5
75-85 %	7
90-100 %	6

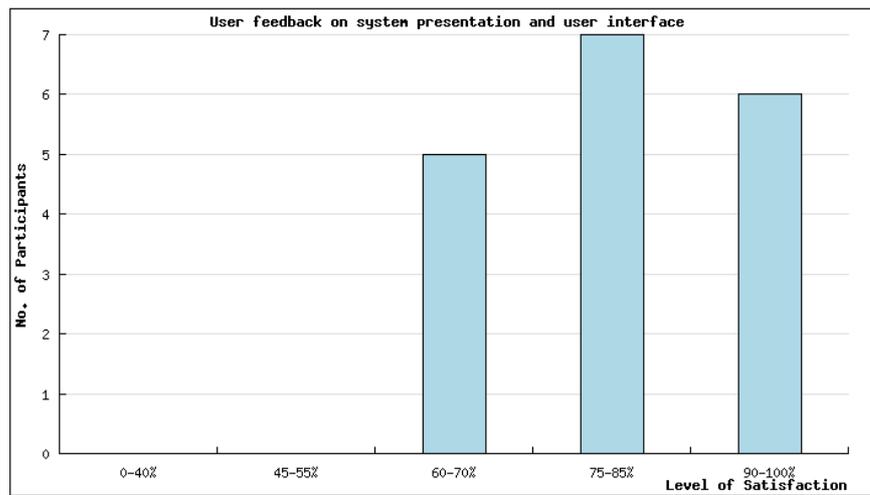


Figure 7-16 Feedback from the participants for the system's user interface

Figures (7-14), (7-15) and (7-16) show the feedback from the participants for the performance, tools and interactivity and user interface of the public transport software system. The feedback was taken in terms of three factors, i.e. system performance in terms of functionality and the provision of the required information, interactivity and ease to access information and output presentation and interface design. Although the number of participants was small, the figures show that almost all the participants had a positive response for the system. All of the users were

pleased by the results obtained by the system. From participant feedback it was found that:

- Very easy to plan trips and to display and track a particular bus on transit map.
- Very easy to obtain and extract transit information.
- Satisfied with the proposed method and data visualisation technologies.
- All the participants were pleased with the present user interface.

## ***7.8 Conclusion***

Our public transport software system is a distributed application. This system comprises various software and hardware technologies such as web applications, databases, vehicle location systems and communication networks. In this chapter, we described designing, implementing and integrating a comprehensive low-cost real-time public transport system. In this system, the operational data streams flow between components. These components include an AVL system as the source of real-time data, tracker, predictor, and web and mobile interfaces for final information formatting and delivery of transit information. The combination of GPS and GPRS provides continuous and real-time tracking. Selecting the technologies and the architecture to support the public transport software system was based on the ease of implementation and operating cost. To evaluate the proposed system usability, we conducted a system usability test with the participation of 18 participants who are regular bus users. Although the number of participants was small, the results show that almost all participants had a positive response to the system. In the next chapter we will discuss the characteristics of the system and results obtained.

# Chapter 8 Discussion

## *8.1 Introduction*

The development of a comprehensive public transport software system relies on communications, data processing, programming, and transit data collection and analysis. Public transport software systems involve several deliverables ranging from web-based display of real-time transit data and arrival time prediction algorithms to mobile-based interfaces. The key features of these systems are a web-based and a mobile-based user interface, real-time location information updates and a map display of transit data. The aspect of communicating spatio-temporal transport data to the map display API is one of the most important parts of real-time public transport systems, as it allows real-time interaction with transit information. In Chapter 1 we identified 6 main objectives of this research project. In this chapter we will discuss the results obtained from the developed system as well as the role of computing technologies (software and hardware) and communication networks in developing and implementing the public transport software system.

## *8.2 Design of Complete System*

It is worth recalling that the primary objective of this research was to build a framework to develop a cost-effective public transport software system which provides transit operators with various tools for monitoring and managing their transit fleet as well as providing the public with better transit services by making transit information available and accessible via a standard web browser and a mobile-based interface. Before system design, we had to identify and discuss the main attributes of a comprehensive public transport system and what techniques which make this system low-cost, easy to use, and practical. The system uses a GPS device as the positioning terminal. However, the approach of using a GPS-based AVL system for tracking and transmitting GPS data to a back-end central server tends to result in higher data transmission costs for information. Therefore, a low-cost GPRS data transmission approach was adopted as the transmission method for GPS data.

In our system, every transit vehicle is equipped with a GPS-based AVL system that is in charge of receiving the geographic position, and relaying the geographic position with other details to a database server for storing and further analysing. Once the data has been stored properly, it can be accessed and processed. A software application has been developed to display real-time vehicle information on a digital map of the transit area. Our public transport software system allows transit operators to monitor their fleet in real-time, giving great opportunity for real-time performance evaluation and service improvement. The system application has provided effective tools to improve the performance of transit vehicles, this includes tools to measure transit system reliability and to measure QoS and also tools to improve transit data visualisation. In order to simulate passenger flow in a real-time environment, a model was developed by generating random numbers representing passenger demands at bus stops. The model simulates the flow of passengers between bus stops and measures the transit vehicle's performance, and how the transport network resources have been utilized.

As for passengers, the system has the ability to display the most important information to passengers, such as the current location of vehicles and vehicle status in terms of adherence to the timetable as well as the expected time of arrival to any stop on the bus route. This information is displayed on a variety of web-based interfaces that were designed for ease of use and to facilitate quick information extraction. For passengers who are in need of information regarding the location of the nearest stop the system provides a location-aware tool for navigating the transit system. This tool brings together the functionality of a real-time transit system and pedestrian navigation. To facilitate the use of public transport services in the field, the system offers a service that enables passengers to receive information on mobile phones. To improve interaction with the transit system, we propose a new interaction model for a mobile device, which provides transit information through haptic feedback which can be useful for certain types of passengers.

Instead of relying on a static timetable that is subject to deviation due to bus operational conditions and the traffic situation, in our system we implemented three prediction models, using bus operational data collected over time to predict bus arrival times at any stop along the bus route. Several factors have been taken into

account when designing this system, including the transit operation cost, ease of use and the possibility of modification and development to keep pace with other public transport systems.

### ***8.3 Developing a Cost-effective Public Transport Software System***

Due to resource constraints, lack of incentive, and the cost of transit tracking deployment, many transit agencies/operators do not provide tracking capabilities to their customers. However, over the past few years, GPS technology has improved markedly and accurate GPS data have become very affordable. A GPS/GPRS integrated system represents a practical low-cost method for collecting transit data and transferring this data continuously through GPRS to a central database. The accuracy, simplicity and affordability of this technology have made it practical for developing real-time public transport systems. Our use of GPS/GPRS technology in the monitoring and tracking of buses in real-time can contribute significantly to a reduction in the cost of transit operations. Through practical examples, this technology has proven its effectiveness in the collection of sufficient amounts of data for the purpose of display and analysis and improve the level of transit service.

In this research, we employed GPS/GPRS integrated technology to be a source of real-time transit data so that by using computer software we managed to use this data to provide transit information to the end user. Maps as an information display media allow data from different sources to be overlaid and combined so that they are used on top of interactive web interfaces to display transit information. Map-based representations have proven their great potential in visualising transportation data. They are particularly well suited to real-time updates, which is the case for moving buses. To reduce the cost of developing the public transport system we employed a free Bing Map API from Microsoft to display the transport region.

### ***8.4 Enhancing Transit Data Visualisation***

The availability of rich GPS archived data allows for new data visualisation techniques and performance analyses. In this research, we provided a variety of ways

to summarise and visualise vast amounts of bus operations data in an insightful manner. As we described in Chapter 4, the system provides transit information through standard web-based views. A map-based interface has been created for dynamic visualisation of transit vehicle movements, allowing users/operators to see stops, routes and moving buses all at once in a close to real-time environment. We provided a graphical and tabular format to present data using a colour-coding technique to visualise performance measures. Techniques such as highlighting values that exceed a certain threshold by varying colours are used to enhance visualisation output. The use of a series line-graphs to capture the daily spatial-temporal “behaviour” showed the effectiveness in the detection of service irregularity such as bus bunching or timetable deviation shown in Figure (4-24) and Figure (4-31). In transport systems, new analysis and visualisation tools are needed to assist with the detection and quantification of transit performance problems. We provided tools to calculate and visualise different aspects of transit services such as excess waiting time, which occurs at a single point (bus stop) in time. We also provided tools to visualise the bus bunching phenomena which can occur at any point along the route. We provide visualisation techniques which incorporate a point or place with a measure itself. For example in Figure (4-37) we visualised vehicle speed at any point in the bus route. We provided different visualisation techniques which can present important findings to transit operators, However, the effectiveness of data visualisation techniques depends on the amount of collected data.

### ***8.5 Measuring Transit Vehicle Performance***

Performance measurement is critical for successful transit system management as it can help transit operators determine whether or not they are meeting their objectives and to evaluate the success of the transit system. Public transport software systems help in shifting transit vehicle performance monitoring from the field to the central server. As discussed in Section (4-2), transit operators do not need to send out field supervisors to track transit vehicle performance. The transport system software application allows operators to monitor their fleet through a web interface where transit data is visualised in various graphical and textual formats.

Our system provides tools to automate the measuring and calculating of quality metrics and transit vehicle performance. As explained in Section (4.4) it is important for transit operators to measure the reliability and performance of the transit system to provide better services. In this research and through practical examples we have proven the possibility of calculating and measuring the transit fleet performance, and quantifying metrics such as excess waiting time, bus headway, and other measures of service to help with analysis and evaluation. The system also has the ability to report the quality of service to a transit regulator on a periodic basis.

### ***8.6 Transit Data Archiving Analysis***

The proposed public transport software system is designed primarily for real-time application. However, it has the capability to capture and/or archive data items that would be valuable for off-line analysis. The system can deal with an enormous quantity and variety of operational, spatial, and temporal transport data, which can be analysed to improve transit services by supporting improved management and service quality monitoring and performance measurements. The collected transport data may help to improve the quality of transit services. As shown in Figure (8-1), the improvement process includes off-line and on-line (real-time) stages. In the off-line stage, the data collected using GPS/GPRS units is archived for further analysis. This archived data could help operators to evaluate and improve operational service. An example of this analysis are measures that are completed across a sequence of stops such as headway reliability.

In the real-time stage, automatically collected data drives operational control, aiding the operators in detecting and responding to deviations from the operational plan; it is also a source of real-time information that can be conveyed to passengers through a variety of media.

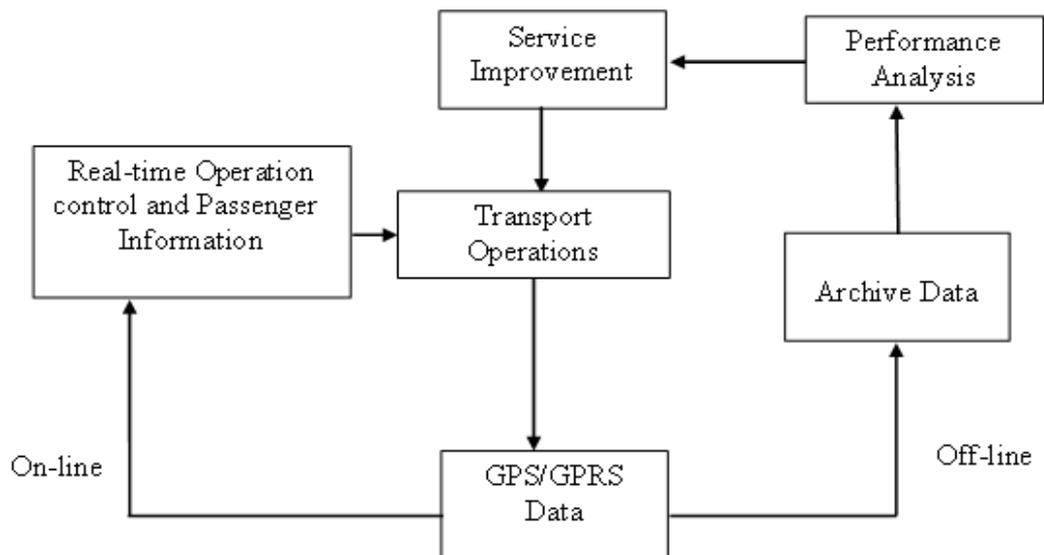


Figure 8-1 Service quality improvement for public transport system

### ***8.7 Improving Fleet Management Systems***

Public transport software systems can help transit operators to manage their fleets in a more efficient way. Our system gives easy access to critical information that aids operators in routing and recovery from incidents. Tracking transit vehicles in real-time can be exploited to enhance transit fleet efficiency; improves the efficiency and safety of the vehicles, which results in a more reliable system that could attract new ridership. When real-time systems are used for tracking transit vehicles, passengers feel secure in knowing the location of the buses. Specifically, this objective relates to improving “emergency response time” when an accident or incident is reported. Vehicle tracking systems can improve safety and security in a variety of ways. For example, as we have shown in Section (4-12), when an incident occurs the exact vehicle location assists authorities in arriving at the scene as quickly as possible.

### ***8.8 Improve Provision of Public Transit Information***

As shown in Section (5-2) the provision of real-time information is more valuable as this information reflects actual journey times and indicates any deviation from

planned service. Real-time information is also expected to achieve reductions in actual public transport journey times through reduced waiting times at stops. Another advantage of real-time information is that it helps the decision-making process and enables passengers to take faster alternative routes. The need for real-time transit information stems from the unreliable nature of bus services caused by unpredictable factors. Due to their popularity as an effective means to deliver information, we have designed a standard web-based interface to provide passengers with transit information. We used AJAX web browser technology to help quickly retrieve and display server-side data within the browser view itself: this allows the delivery of real-time transport information to all users.

As described in Section (5-6) our system provides passengers with navigation instructions to the nearest bus stop and advises passengers when they must start walking to that bus stop to catch the bus on time. This information is provided based on the bus actual running time and not on the published timetables, so the efficiency of this feature depends on the accuracy of predicting bus arrival times. This system brings together bus tracking and pedestrian navigation into the same application. The user can input the start point/current location and destination point and the system finds the nearest bus stop where the user needs to catch their bus to the destination point. The system provides the shortest path and time needed to reach the bus stop and advises the passenger when to start walking to the bus stop. The provision of such transit information is expected to improve the perceived quality of service and lead to more satisfied passengers.

Mobile phones play important role connecting the user with the service sector surrounding it, which includes transportation services. In Chapter 5, we discussed the practical possibility and ability of mobile devices to improve real-time transit information. Four approaches for the use of mobile devices for transit services were explained. These include delivering real-time transit information on smart mobile phones, using haptics feedback in the form of vibration alarms with different patterns and frequencies to give different kinds of location based information to the user, integrating real-time bus data with a 'point-to-query' transit information system, and using haptics techniques as an alternative to visual map interfaces for public transport systems.

The first approach that we provided concerned delivering real-time transit information on smart mobile devices using information such as the current location and timestamp of both bus and user to provide bus route information. The second approach concerned the use of mobile phones to help passengers know their desired destination is nearing. It provides information about time and distance to the destination bus stop and uses haptic feedback in the form of vibration. The third approach concerned extracting bus arrival time information by pointing the phone in the direction of points of interest. The fourth approach was concerned with developing a comprehensive interaction model for users of public transport systems. It enabled multimodal interaction techniques of communication and integrated a haptic interaction model for various phases in the user's journey. The haptic-feedback based system assists in providing location-based information in a subtle way for passengers using public transport (specifically buses).

The main benefit of these systems is that passengers can receive transit information on their mobile device to reduce anxiety about the actual arrival time of buses, and also if they are not familiar with the area and do not want to miss their destination stops. Also, passengers can be notified by the vibration alarm when the bus is approaching their stop.

## ***8.9 Conclusion***

Enhancing the mobility and the accessibility of transit services places demands on public transit systems. These systems have to be upgraded, improved and expanded to serve these demands. In this research, we have built a framework to develop a cost effective and comprehensive public transport system using several integrated technologies. Our system has the ability to collect real-time transit data, analyse, and visualise transit data and provide passengers with valuable information such as bus current location and estimated time of arrival. The system provides transit operators with tools for monitoring, analysing and measuring overall transit system performance. The proposed system is expected to improve transit service such that it

will have a resurgence of use. In the next chapter, we conclude this work and suggest future work that may be undertaken to improve the system.

## Chapter 9 Conclusion and Future work

### 9.1 Introduction

This final chapter is divided into two sections. It offers a set of conclusions, both specific and general, made from the results presented in the earlier chapters and outlines some directions for future work.

### 9.2 Conclusion

This research explored the use of various integrated software and hardware technologies such as GPS-based AVL systems with integrated wireless communication networks for improving public transport systems. The research used GPS data acquired through a new cost-effective data collection scheme using GPRS. We have demonstrated a number of tools that show their utility. Specifically, we have described a cost-effective public transport software system, which provides real-time passenger tools across a variety of devices and interfaces to evaluate system performance using various quantitative performance measures and data visualisation methods. According to (TCRP Synthesis 48 2003) the total capital cost of the underlying AVL systems is shown. The total capital cost divided by the number of equipped vehicles to derive the AVL system cost per vehicle is given in following table.

Table 9-1 Total Capital Cost of Automatic Vehicle Location(AVL) Ssystems

System	No. of AVL Equipped Vehicles	Type of AVL	Total Capital Cost	Cost per Vehicle
Tri-Met	68 9	GPS	\$7,00 0,000	\$4,500
Dublin Bus	156	GPS	\$660,300	\$2,919
Kent County Council	141	DGPS	\$2,000,000	\$5,000
London Buses	5,700	Signpost	\$23,251,500– \$27,901,800	\$4,650

As we can see from Table 9-1, the high cost of AVLs can be an obstacle to improving transport services however, adopting cost-effective, cheap and affordable integrated technologies help turn to achieve this goal. In the case of the research we reached the following conclusions:

- Advanced GPS/GPRS technologies have matured to the point where they are affordable and can be used for collecting real-time transit vehicle data. The integrated data collection system requires minimal manpower. Moreover, the data obtained by such systems is more reliable, as they require less human intervention. These technologies are expected to increase the quality of the transport services and improve data-based transport management systems.
- In this research we presented a client/server cost-effective system for monitoring real-time public transport using off-the-shelf integrated technologies. The system provides transit operators with tools to measure transit vehicle performance and report QoS indicators to the regulators.
- Data visualisation techniques do not generate or create new data, but allow the geographic attributes inherent in the data to be displayed and analysed intuitively where information can be easily retrieved. Dynamic and static visualisation techniques have the potential to improve transit services by displaying transit information on a map and providing innovative data visualisation views, which may help transit users and operators to extract transit information easily and consequently improve the perception and the credibility of a transit system. This research provides both approaches for visualising transit data for information dissemination and bus operations performance measures: 1) A static visualisation method using colour coding diagrams which can disaggregate off-line data down to an hourly level for different segments, aggregate over time or space, or provide single stop analysis; and 2) A dynamic, interactive visualisation method using the Bing Maps API demonstrating bus information and operations performance along a route for any chosen bus.

- In our system, three prediction models have been implemented for predicting bus arrival times of transit vehicles between any two bus stops. The performance of the prediction models was tested and their overall prediction accuracy was evaluated. We have also demonstrated a real-time trip planning tool and also a method for real-time navigation of a transit system. Additionally, we have presented a simulation of passenger-flow for evaluation of public transit system operations in a real-time environment; this can help transit operators to maximize transit network utilization. Tools are provided to the transit operator for measuring and calculating transit fleet performance and reporting the Quality of Service metrics to regulators.
- Our system brings together the functionality of an AVL system and pedestrian navigation to provide the user with information that will inform the user with the arrival time of the next bus and also reduce the waiting times at a bus stop by providing the passengers with information about the time taken to get to the bus stop by walking.
- The system architecture was designed and developed in a way to be applicable to different transit services or regions. Changes may be made to the structure of the databases easily.
- The rapid development of various smart phone devices equipped with sufficiently accurate sensors makes mobile phones an essential tool for interacting with transport systems in intelligent ways. Internet enabled mobile phones can receive real-time transit information, enabling passengers to interact with public transport systems on their mobile. In this research, we presented a number of applications that use smart mobile phones to deliver and navigate transit systems using location and context aware tools. The haptic-feedback based system assists in providing location based information in a subtle way for passengers using public transport (specifically buses). The vibration alarm provided by the mobile applications helps notify passengers

about the bus approaching their destination bus stop as well as pedestrian navigation assistance.

### ***9.3 Future work***

This research presented software and hardware technologies and along with a methodology for developing a cost-effective public transport software system using GPS and GPRS. The system can be developed further so that transit users and operators can derive the maximum advantages from its application. In order to do so, possible future enhancements can be made.

Experiments that evaluate the effectiveness of web-based and mobile-based interfaces will help to determine which visualisation techniques are most and least effective. A large-scale survey and usability study will help to assess the effectiveness of web-based public transport systems in comparison with traditional dissemination techniques.

For a wider insight and to create a more realistic scenario for analysing the overall passenger service time the set of used parameters for simulating the passengers-flow could be made to be adjustable. Adjusting parameters such as bus's utilised capacity or the adherence to the timetable should lead to better simulation results and provide the operators with a clearer picture of the system performance.

For haptic-based mobile applications more user trials are required to verify the effectiveness of these applications to communicate with the transportation systems and provide transit information. Furthermore, a complete door to door travel planner using haptics/gesture based interactions could form a central focus for future work.

For the trip planning service, integrating third-party data sources such as weather, distance and speed between stops will increase accuracy and provide a better basis for planning trips. Additional testing is required to investigate the performance of the algorithm for finding the nearest bus stop in larger regional transportation areas, which includes many transit agencies and intercity networks.

For better and more efficient mobile applications, transit region maps can be stored and rendered in a suitable manner on mobile devices to enable users to access the system using vector graphics (W. Y. Yan, 2004).

New techniques such as The General Transit Feed Specification (GTFS) (Google, 2012) defines a common format for public transportation schedules and associated geographic information. GTFS allows public transit agencies to publish their transit data and developers to write applications that consume that data in an interoperable way. This will facilitate developing standard methods in the development of transportation systems.

It is recognised that the lack of collected traffic data as well as weather data influenced the accuracy of prediction of arrival times; therefore, data from other sources, such as real-time traffic conditions, should be incorporated into our prediction models and algorithms. More research is recommended in this area to improve arrival time prediction accuracy. One suggested approach to improve arrival time estimation is to combine the three proposed prediction models using a proper data fusion technique. A dynamic updated weight can be assigned to each model. Combining many models reduces the instability of the prediction and therefore should yield better performance of prediction (S. Lim and C. Lee, 2011; Salaik, B., 2004).

Certain types of transit information can be analysed and visualised in the third dimension, thereby providing additional insight that cannot be shown in two dimensions. 3D visualisation is an appropriate technique for analysing and visualising transit performance information at point locations such as stops, time points, maximum load points, and event location (Said, M. et al, 2002). The Z-dimension can be modeled as passenger's counts, schedule deviation, and variances. Work can be done on developing 3D models for analysing and visualising transit data.

The estimated arrival time at bus stops was calculated based on the current bus location identified through GPS technology and the published timetable. Further refinement and studies are recommended to improve the prediction models for better prediction results.

A number of limitations can be pointed out in this research. One of the limitations is that not all buses on the transit service in Blackpool are equipped with on-board GPS/GPRS tracking units. Only 9 of the fleet are currently equipped with these units, but if more buses were fitted with them, a more in-depth transit service analysis could be obtained. In addition to using GPS/GPRS data in the real-time or off-line analysis of transit vehicles, it could be used for traffic monitoring and detection of traffic queues, as the locations of traffic jams and bottlenecks would be of interest to transit operators and supervisors.

Lastly, as no real passenger data was available, additional data could be collected to enrich the analysis and provide the opportunity to observe the impact of this data on different measures of reliability. It remains to obtain and integrate such data at some point in the future.

#### ***9.4 Future of Public Transport Systems***

One of the best ways to encourage people to use public transport systems is to make it attractive by improving the system. Technologies for providing real-time transit information have progressed rapidly and economically feasible solutions are now available. These technologies can help in improving transport systems by adding key features and attributes to make transport systems close to ideal. In this research we discussed and addressed the development of a close to ideal public transport system using various integrated technologies. We discussed attributes such as cost-effectiveness, providing real-time information, and measuring transit system reliability. However, many of the attributes and features are still needed to reach the ideal system. For example, disabled passengers could benefit from smart tools to help them use public transportation systems. Integrating social networks with transit

systems may improve public transit services where passengers can share knowledge about the time of arrival at locations and the transit system could adjust the expected locations of transit vehicles and publish reports for the passengers. Further research can contribute to improving public transportation systems by developing more services for them. Achieving these goals will make public transport services more attractive to the public of 21<sup>st</sup> century and promote its uptake leading to much desired environmental and social benefits.

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# Appendix A