Expanding the Spatial Data Infrastructure model to support spatial wireless applications

Jessica Davies

Submitted in total fulfilment of the requirements for the degree of Doctor of Philosophy

November 2003

Department of Geomatics
The University of Melbourne

Abstract

In response to a growing recognition of the importance of spatial information, the concept of Spatial Data Infrastructure (SDI) has evolved. Designed to facilitate an environment that promotes access and sharing of spatial information, SDI development has benefited from, and in due course adopted, advances in information technology (particularly improvements in desktop computing capabilities and communication networks such as the Internet).

The never ceasing progression of technology now enables communication and data access via mobile phones and a myriad of portable, networked computing devices. Indeed over the last few years, the proliferation of mobile phones has exceeded many expectations and is enabling nomadic users to communicate and access data services with ease. Location is one of the unique characteristics of mobility that is encompassed by this form of wireless communication and has been capitalised on in the form of enhanced safety initiatives. In turn, the infrastructure required for these safety services has encouraged additional Location Based Services (LBS) to flourish.

LBS act as spatial decision making tools, providing information to end users based on their location, or on the location of some target. LBS are not restricted to the wireless environment however this is their current area of promotion. The principles of accessing spatial information that are encompassed by LBS mirror those of SDIs, and as a result SDI models need to accommodate for this new medium of information access and delivery.

This research aimed to expand the SDI model to support applications that assist with spatial decision making, such as LBS. Focused specifically on LBS that are accessible for wirelessly networked, portable devices, this research implemented a theoretical and practical approach to identify the additional requirements for SDIs in this domain. A prototype LBS application for public transport information and navigation was developed and evaluated as part of this process. It is proposed that the resulting model (which details the additional requirements as well as their relative importance) act as an example framework for future LBS implementations so that they may gain the benefits from a standard, integrated infrastructure as offered by SDIs.

Declaration

This is to certify that:

(i) The thesis comprises only my original work;

(ii) Due acknowledgement has been made in the text to all other materials used;

(iii) Ethics approval was obtained and granted for the evaluations and questionnaires (where necessary);

(iv) The thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Jessica Davies

Please note name change from Smith to Davies following my marriage on the 22^{nd} of March 2003. As a result, the majority of publications in relation to this research use my maiden name - Smith.

Acknowledgements

I would like to thank the many people who assisted and supported me during my doctoral candidature. Firstly, I offer my appreciation and thanks to my supervisors, Dr Allison Kealy and Professor Ian Williamson for their support and guidance. Secondly, to the members, past and present, of the Centre for Spatial Data Infrastructures and Land Administration (Clare Brazenor, Neil Brown, Lillian Cheung, Kate Dalrymple, Dr Serryn Eagleson, Dr Wolfgang Effenberg, Professor Francisco Escobar, Mary-Ellen Feeney, Dr Tai On Chan, Shamsul Abdul Majid, Dr Abbas Rajabifard, Daniel Paez, Dr Malcolm Park, Dr Lisa Ting, Daniel Steudler, Mathew Warnest and Sigit Widodo) for their assistance with my research and their friendship. Thanks are also due to Land Victoria, Department of Sustainability and Environment, State Government of Victoria for their financial support for the provision of equipment required for this research.

I also wish to express my gratitude for the support provided by all members of the Department of Geomatics, including the visiting researchers who provided a valuable sounding board for research ideas and direction. In particular I would like to thank Dr William Mackaness for his active involvement and support for my research, which began with his sabbatical to the Department and continued throughout my candidature despite our geographical remoteness.

This research would not have been possible without the generous support of Webraska Mobile Technologies SA (Webraska™) for the use of their 'SmartZone™ GeoSpatial Platform' and Sensis™ for their Whereis® Location Server; special thanks go to Kirk Mitchell and Jeremy Klitzing respectively for their involvement in organising access to, and support in the use of these products. Thanks also to the Department of Information Systems, The University of Melbourne, in particular Connor Graham, Sonja Pedell and Jesper Kjeldskov for their assistance with the usability evaluation. A special thanks should also be given to all the evaluation participants, particularly those who undertook the usability evaluation in the field on those hot summer days.

I would also like to thank Karen Urquhart and Dr Stephan Winter for their fresh insight and editing suggestions in the production of this thesis.

Finally I would like to thank my husband Travis for his tireless patience, understanding, support and encouragement.

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Nomenclature

3G — Third Generation

The next generation of mobile communications that offers broadband, packet-based transmission of text, digitised voice, video, and multimedia at data rates up to and possibly higher than 2 megabits per second.

bps — Bits Per Second

A measure of data speed for computer modems and transmission carriers. As the term implies, the speed in bps is equal to the number of bits transmitted or received each second.

A-GPS — Assisted Global Positioning System

Handset positioning technique for mobile stations based on an integrated GPS receiver.

API — Application Programming Interface

A set of routines, protocols, and tools used to build software applications. A good API makes it easier to develop a program by providing all the building blocks and enabling a programmer to put the blocks together. Although APIs are designed for programmers, they are ultimately helpful to users because they guarantee that all programs that use a common API will have a similar interface.

AUSLIG — Australian Land Information Group

Australia's former national mapping agency. Now Geoscience Australia.

CERN — European Organization for Nuclear Research

E911 — Enhanced 911

A mandate in the United States that seeks to improve the effectiveness and reliability of the wireless 911 service by providing 911 dispatchers with additional information on wireless 911 calls.

E-OTD — Enhanced Observed Time Difference

Handset positioning technique for mobile stations based on measurements of observed time differences between pairs of local base stations.

ETSI — European Telecommunications Standards Institute

Standards body established to coordinate the development of telecommunications systems within Europe. These systems relate to fixed, wireless and cellular systems. Recently systems such as GSM and DECT have been devolved to the 3GPP (Third Generation Partnership Project), a collaboration of standards bodies including ARIB (Association of Radio Industries and Businesses) from Japan.

FCC — Federal Communications Commission

A US government agency that supervises, licenses, and controls electronic and electromagnetic transmission standards.

FGDC — Federal Geographic Data Committee

A US interagency committee composed of representatives from the Executive Office of the President, Cabinet-level and independent agencies tasked with developing the National Spatial Data Infrastructure (NSDI) in cooperation with organisations from State, local and tribal governments, the academic community, and the private sector.

FTP	File Transfer Protocol A standard Internet protocol (that uses TCP/IP) to exchange files between computers on the Internet. FTP is commonly used to transfer Web page files from their creator to the computer that acts as their server.
GDSC	Geospatial Data Service Centre A mediator between data users and suppliers that ensures the integrity of data access by monitoring the technical as well as administrative processes defined by the SDI that exist between suppliers and users.
GIF	Graphics Interchange Format A standard for digitised images compressed with the LZW algorithm, defined in 1987 by CompuServe (CIS).
GIS	Geographic Information System An integrated computer software package that is specifically designed for use with geographic data and is capable of performing a range of data-handling tasks (including data input, storage, retrieval, and output) and statistical and analytical processes.
GPRS	General Packet Radio System Defined by 3GPP (Third Generation Partnership Project) and is employed to connect mobile cellular users to the Public Data Network. It provides packet switching data services across the fixed and radio network.
GPS	Global Positioning System An all-weather, global satellite based positioning system developed by the US Department of Defence. Users with a GPS receiver use timing information from the satellites in order to triangulate their position on the earth surface.
GSDI	Global Spatial Data Infrastructure An SDI encompassing the entire Earth.
GSM	Global System for Mobile Communication A second generation cellular telecommunication system which was first planned in the early 1980s. Unlike first generation systems operating at the time, GSM was digital and thus introduced greater enhancements such as security, capacity, quality and the ability to support integrated services. Initially, GSM was planned to be a European system allowing subscribers to roam between different networks however, GSM was quickly adopted by many other regions and is now a “Global System”. Today, there are over 400 GSM network operators or carriers located in 182 countries and supporting collectively nearly 700 million subscribers.
HTTP	Hypertext Transfer Protocol The standard protocol for the carriage of data around the Internet. The protocol supports a variety of data types, media and file formats. HTTP terminates at the client and server, these are typically a user’s web browser and the web server. HTTPS (Secure HTTP) is an additional protocol function used to encrypt the HTTP payload.
HTML	Hypertext Markup Language An authoring language in which tags are used to format data and pictures within an HTML page. In addition, commands to download applications, generate hyperlinks and provide dynamic user interaction may also be included. These tags and commands are interpreted by the user’s browser in order to display data, or initiate actions based on the HTML commands.

ISO	International Organization for Standardization A non-governmental organisation made up of a network of the national standards institutes of 147 countries, tasked with developing technical standards.
ISP	Internet Service Provider A company that provides Internet access to other companies and individuals.
IT	Information Technology Generally refers to industries using computers and their associated software.
ITS	Intelligent Transportation System A broad based term used to describe developments in communication and computing technologies applied to transport services generally. The primary focus of ITS is to provide improvements in safety, efficiency and environmental performance of all modes of transport including air, sea, road and rail.
LAN	Local Area Network A group of computers and associated devices that share a common communications line or wireless link and typically share the resources of a single processor or server within a small geographic area (for example, within an office building).
LBS	Location Based Services Services concerned with supporting dynamic spatial decision making through the provision of real-time, geographically based information.
LSDI	Local Spatial Data Infrastructure An SDI for a small geographic area such as a local government jurisdiction.
MS	Mobile Station Mobile, portable device (typically a mobile phone) used for wireless communication.
MMS	Multimedia Messaging Service Service that allows Message Entities (e.g. mobile terminals) to send messages comprising a combination of text, sounds, images and video to capable mobile terminals.
NSDI	National Spatial Data Infrastructure An SDI for an entire nation.
OGC	Open GIS Consortium An international industry consortium participating in a consensus process to develop geoprocessing specifications to support interoperable solutions for 'geo-enabling' the Web, wireless and location based services and mainstream IT, and empowering technology developers to make complex spatial information and services accessible and useful with all kinds of applications.
OOSE	Object-Oriented Software Engineering A method of software engineering that employs a series of models containing objects representing real world entities and their interactions.

OpenLS	Open Location Services	A multi-phase project (of the OGC) focused on the development of interface specifications that facilitate the use of location and other forms of spatial information in the wireless Internet environment. The purpose of the initiative is to produce open specifications for interoperable location application services that will integrate spatial data and processing resources into telecommunications and Internet services infrastructure.
PDA	Personal Digital Assistant	Handheld computing device to assist with organising and scheduling events, recording addresses etc. A computerised diary.
PPP	Point to Point Protocol	Designed to provide router to router and host to network connections over synchronous and asynchronous circuits.
RSDI	Regional Spatial Data Infrastructure	An SDI encompassing several national administrative areas.
SDI	Spatial Data Infrastructure	An environment of networked spatial databases and data handling facilities, that includes the institutional, organisational, technological, human, and economic resources which interact with one another and underpin the design, implementation, and maintenance of mechanisms facilitating the sharing, access to, and responsible use of spatial data at an affordable cost for a specific application domain or enterprise.
SIM	Subscriber Identity Module	A user's subscription to the mobile phone network, usually in the form of a small chip card. The SIM card contains information that enables access onto the subscripted operator's network.
SMS	Short Message Service	Service that allows Short Message Entities (e.g. mobile terminals) to send short text messages to other Short Message Entities. SMS is implemented in the GSM network as a store and forward text messaging system. SMS messages are limited to 160 characters (or 140 bytes) in length, although it is possible to concatenate several messages to produce one longer message.
SSDI	State Spatial Data Infrastructure	An SDI for a geographic area controlled by a particular State government.
TCP	Transmission Control Protocol	A reliable octet streaming protocol used by the majority of applications on the Internet. It provides a connection-oriented, full-duplex, point to point service between hosts.
TOA	Time of Arrival	Network positioning technique for mobile stations based on measurements of the time of arrival of a signal from a mobile station to three or more base stations.

UMTS Universal Mobile Telecommunications System

A 3G mobile communications system which provides an enhanced range of multimedia services. UMTS will speed convergence between telecommunications, IT, media and content industries to deliver new services and create fresh revenue generating opportunities. UMTS will deliver low cost, high capacity mobile communications offering data rates as high as 2Mbps under stationary conditions with global roaming and other advanced capabilities. The specifications defining UMTS are formulated by 3GPP.

URL Uniform Resource Locator

A standard way of specifying the location of an object, typically a web page, on the Internet. URL are the form of address used on the World Wide Web (WWW). They are used in HTML documents to specify the target of a hyperlink which is often another HTML document (possibly stored on another computer). An example of a URL is http:\\www.unimelb.edu.au

W3C World Wide Web Consortium

A world wide forum of organisations, created in October 1994, to lead the World Wide Web to its full potential by developing common protocols that promote its evolution and ensure its interoperability.

WAP Wireless Application Protocol

A standard designed to allow the content of the Internet to be viewed on the screen of a mobile device such as mobile phones, personal organisers and pagers. WAP also overcomes the processing limitation of such devices. The information and services available are stripped down to their basic text format.

WBMP Wireless Bitmap

A bitmap image for display on a WAP enabled mobile phone.

WML Wireless Markup Language

An authoring language in which markup tags are used to format data and pictures within a page. These tags are interpreted by a WAP browser for display.

WWW World Wide Web

An international, virtual network based information service composed of Internet host computers that provide on line information.

XML Extensible Markup Language

An authoring meta-language (a language for defining markup languages) in which markup tags are used to specify content, its location and format.

Chapter 1 Introduction

The aim of this research is to assess how the current Spatial Data Infrastructure model (as defined by Rajabifard and Williamson (2001)) needs to expand in order to support spatial decision making in the form of wireless Location Based Services. This chapter provides an overview of the problem under investigation, the research method adopted and a summary of the subsequent chapters of this thesis.

1.1 Background

Spatial Data Infrastructures (SDIs) provide an environment in which complete and consistent spatial data sets (data consisting of elements distributed in two or more dimensions, the location of which can be expressed implicitly or explicitly using a coordinate system) can be accessed and retrieved by various user groups based on a foundation of policies and standards. Essentially SDIs are a driving force facilitating and coordinating the exchange and sharing of spatial data to a wide group of users – from data generators through to decision makers. While SDIs have been developing over the last decade, wireless communication technologies have also been undergoing a rapid evolution. The convergence of wireless communications, positioning technology and network computing has resulted in the provision of new facilities and new applications that are using spatial information (ordered and contextualised spatial data that provides meaning). As a result, new challenges and opportunities are arising for spatial data providers and users.

Wireless access to data is a rapidly emerging field, particularly with the recent escalation and prominence of the wireless Internet and technologies such as the Wireless Application Protocol (WAP), I-mode, General Packet Radio System (GPRS), Universal Mobile Telecommunications System (UMTS) and third generation (3G) services. Wireless mobile communication is strongly associated with location (by virtue of the fact that the communicator can be linked to a location when initiating a communication session, and that this location may change during the session), and already many wireless providers are using Geographic Information Systems (GIS) to supplement services to clients. Relevant information, with respect to time and location, can now be delivered to users via devices such as mobile phones and Personal Digital Assistants (PDAs). These services are capable of performing a range of tasks from personal safety (e.g. Enhanced 911) through to convenience services (e.g. guiding users from their current location to their restaurant of choice). Many applications that have been developed to date use and/or deliver spatial information to mobile users, however the information is queried in a simple manner dictated by the application developer. Additionally, none of the applications currently access data through established SDIs. More often than not, the individual organisations providing the applications have collected the data sets that they require from various sources and established their own GIS to support their specific application – essentially setting up their own isolated infrastructure. Despite being both a feasible and practical short term solution from the perspective of a wireless application developer, this arrangement lacks continued assurance of information quality, and encourages the duplication of data sets. SDIs aim to overcome these problems by allowing data sets to remain the responsibility of the relevant custodian.

One of the most important issues in relation to delivering information to wireless users is that of data currency. It is imperative that a mobile user be provided with accurate, up to date data. While this is also an important issue for non-mobile users, it is significantly important for users 'on the move'. Thus rather than individual organisations duplicating and maintaining their own data sets, having access to them through a standard SDI would be most beneficial. Naturally, different applications will have varying spatial data usage requirements, however it is envisaged that there will be many infrastructure elements (such as query and delivery mechanisms) that are common for a range of applications.

The infrastructure requirements for wireless applications that utilise spatial information need to be determined and integrated into the models defining SDIs so that they may reflect and support the changing nature of spatial information use. Therefore the aim of this research, described in more detail in Section 1.4, is to determine the additional features required for SDI so that it may support wireless, real-time, spatial decision making.

1.2 Problem Statement

The rapid uptake of wireless devices for the dissemination and utilisation of information, and the related potential for location and other spatial information has been relatively unforeseen. As a result, SDIs have not been designed to promote the dissemination of information through wireless mediums (and the particular challenges that such communication poses).

To date SDI models have been developed within an environment of fixed, networked computers operating static applications. In order for SDIs to support location specific, dynamic applications or Location Based Services (LBS), accessible via wirelessly networked, mobile devices, a revised SDI model is required. While end users need not be aware of the underlying infrastructure providing their service, it is the providers of such services who would benefit from an SDI that supported wireless information access and dissemination.

Beyond the technical communication specifications, there is also currently no unifying architecture for LBS. Like SDI, LBS are concerned with issues of 1) people and user environments; 2) networked access to data; 3) policy, privacy and liability; 4) standards and interoperability; and 5) data quality. Therefore using the SDI model as a framework could also result in the definition of an architecture for LBS.

1.3 Problem Justification

While it could be argued that current LBS marketing campaigns rely on a 'technology for technologies sake' approach and play on society's willingness to adopt new technology, LBS can be described as tools that aim to enhance the decision making power of individuals. By allowing people to access and act on information without the constraints of a fixed location and desktop computer, LBS pose a unique and comprehensive decision making environment.

LBS are offering a range of applications on handheld devices. These applications have evolved from many requirements across areas of safety, information, tracking and billing, and capitalise on the location of mobile telecommunication devices. For example, emergency roadside assistance, early warning evacuations, locating attractions along a route of travel, weather alerts, traffic information, routing and navigation services, inventory/package monitoring, vehicle and fleet management and location sensitive advertising can all be classified as LBS applications.

Ultimately, these applications assist spatial decision making. GIS and SDI initiatives have developed to facilitate these sorts of applications however they have both focused on the computing environments of their time – static, independent computing or reliable, fixed line network connectivity. Offering decision making power via portable handheld devices (such as mobile phones) presents specific challenges above and beyond those that have been identified for SDI to date. Many of these relate to the end user of the spatial information. SDI development has not focussed significantly on end users since this user group has predominantly been made up of spatially trained individuals (it is promising to observe that this trend has been changing over the last few years, with end users becoming more of a focus in SDI research). LBS however have the potential to significantly expand the spatial information user base and thus the need for SDI models to adapt to these new conditions is paramount.

The format and delivery of spatially related information across wireless communication networks is also dramatically different to the fixed line Internet environment within which most existing SDI operate. Portable, handheld devices employ small, predominantly monochrome visual displays (although colour displays are becoming more popular) and a keypad for data entry. It is therefore commonly inappropriate to present mobile users with a sophisticated GIS. Additionally the wireless communication networks used to transmit data to portable handheld devices cannot support the transmission speeds that users have come to expect on desktop computers, therefore finding the optimal quantity of information that can be delivered to users without excessive delay or cost is also a challenge.

The location component of LBS helps to overcome some of these challenges. Restricting information to a small set of specific locations, or a location and some theme, can reduce large GIS datasets down to a more suitable size for wireless transmission and small screen presentation. Adding additional constraints (such as time) reduces datasets even further. Unfortunately these approaches do not help to clarify the relevance of information, nor issues such as how best to present navigation information on a mobile phone to users who are combining their interaction with the device with their interaction in the physical world nor how LBS should cater for the range of spatial abilities of users.

The evolution of Internet connectivity to wireless devices, and the potential for a vast array of applications (many of which will rely on spatial information) to assist users with their everyday tasks, as described above, provides the impetus for this research.

1.4 Research Aim and Scope

The aim of this research is to determine the additional features required for the SDI model in order for it to support wireless, real-time, spatial decision making in the form of LBS.

While there are many definitions for SDI depending on their scale and intended use, researchers have identified five components common to all SDI initiatives (people, access networks, policy, standards and data). Explained in greater detail in Chapter 3, it is Rajabifard and Williamson's (2001) schematic representation that is referred to in this thesis as the 'SDI model'.

Similarly, the term LBS can encompass a wide range of applications designed for end users (as described in Chapter 2). This research has focussed on LBS that are accessible via a wireless communication device (e.g. a mobile phone or Internet enabled PDA) as opposed to those that operate over fixed or guided communication channels (e.g. telephone lines).

In order to achieve the aim stated above, a number of research objectives were identified:

- Evaluate the SDI model in terms of its applicability to wireless LBS;
- Identify, at a theoretical level, expansions to the SDI model for it to support wireless LBS;
- Develop a working prototype LBS;
- Evaluate the prototype LBS in terms of the proposed expanded SDI requirements and the usability of the application; and
- Use the prototype evaluations to revise the SDI requirements and develop an expanded SDI model that supports wireless LBS.

1.5 Contribution to Knowledge

This research contributes to the SDI field of knowledge by providing an extended model that supports the real-time dissemination of spatial information over wireless devices. This revised model should help to promote spatial information access and use by a broad range of mobile users, who are beginning to develop high expectations of the range of information and services available to them in their dynamic environment.

The framework for the model has been based on the categories of people within the LBS value chain (which encompasses end users through to content providers). The model characteristics have been based on the development and evaluation of a prototype LBS that provides information and navigation directions for public transport travel in Melbourne, Australia. While this is a narrow LBS application area, the implications on the SDI model have also been regarded theoretically to account for other categories of LBS applications. The applicability of this model for other wireless, spatial applications may however require further verification, and recommendations on how this could be achieved have been made.

Of benefit also to the wireless application deployment area, this research (and in particular the resulting model) will provide an example framework for LBS development and deployment.

1.6 Thesis Structure

In order to achieve the research aim stated above, the background concepts and theories for both LBS and SDI need to be examined in order to understand the current situation in both fields. This understanding then leads on to the formulation of a hypothesis that can be tested, the consequences of which feed back into the understanding and ultimately result in an expanded SDI model that supports wireless, real-time, spatial decision making.

Following this introductory chapter, Chapters 2 and 3 respectively review the background concepts and theories for LBS and SDI. Chapter 2 examines LBS from the perspective of the three contributing components: position, information and communication. The focus of this chapter is on wireless LBS, or LBS that can be accessed on Internet enabled, handheld, portable devices. Within Chapter 3, the evolution of the SDI concept in response to recognition of the importance of spatial information is explored along with an explanation of the components that comprise the contemporary definition of SDI. The SDI model is evaluated in light of wireless communication methods, and the technical components required for information sharing (a pivotal component of SDI) are described.

Drawing on the synergy between the concepts of SDI and LBS and the need to extend the SDI model for wireless communication (identified in Chapter 3), Chapter 4 introduces the hypothesis of the research, and the method by which the hypothesis will be assessed. A practical approach is proposed involving the development of a prototype LBS for public transport route finding. This chapter introduces the dual evaluation approach that was undertaken in order to verify the hypothesis: walkthrough evaluation and usability evaluation.

Following the explanation and justification of the research approach, Chapter 5 explains the development lifecycle of the prototype. This chapter covers the requirement specification, analysis and design, implementation, testing and the assumptions and limitations of the prototype.

The results from the prototype evaluations are presented and discussed in Chapter 6. Further discussion, including a comparison of the evaluations, the SDI model refinements that have been revealed, and the research method in general is provided in Chapter 7. Conclusions and further recommendations of the research are drawn in Chapter 8.

The flow of the thesis, and the major research tasks are shown in Figure 1-1.

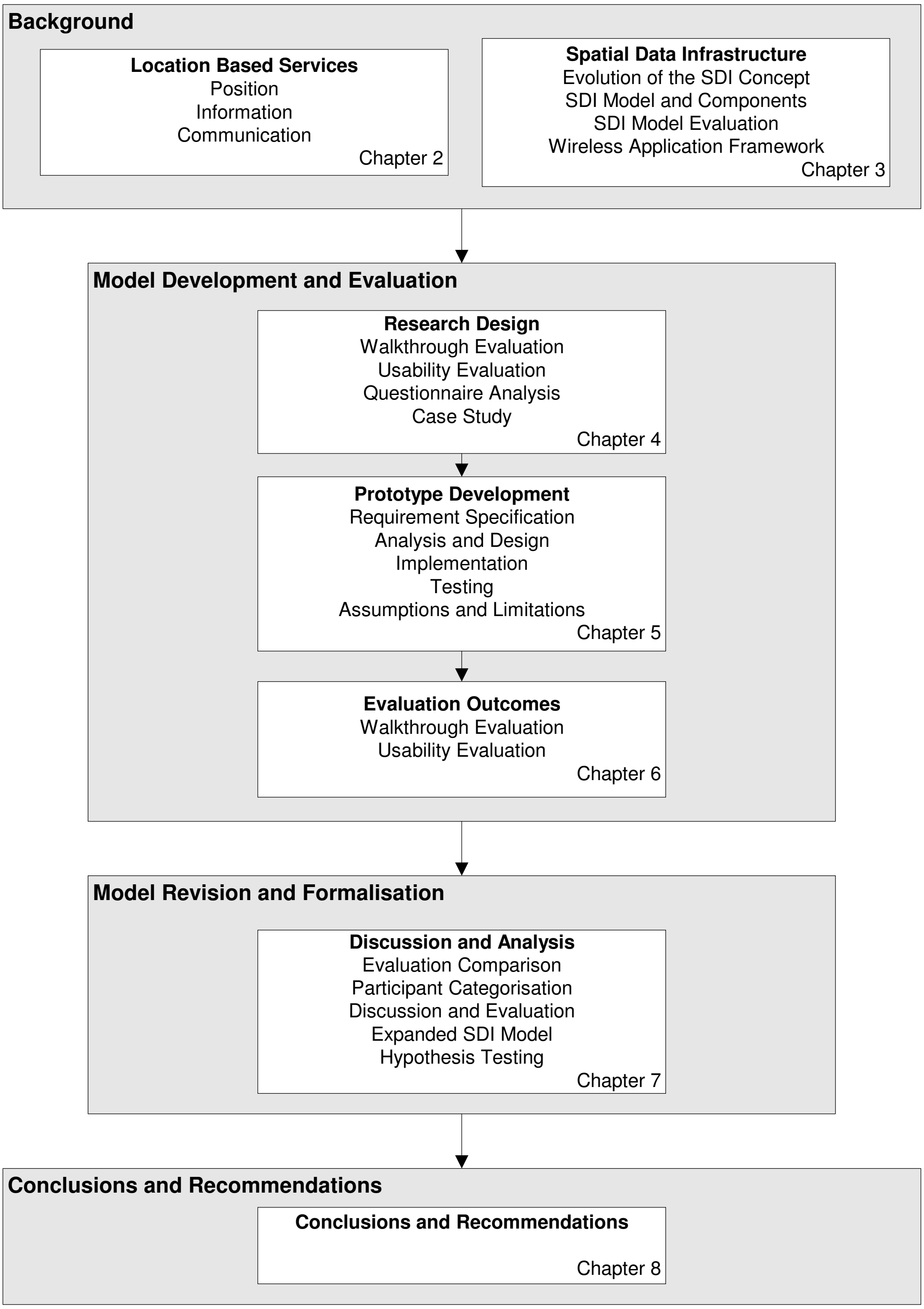


Figure 1-1 Thesis flow

1.7 Summary

This chapter has provided a context for the research, highlighting the need for a revised SDI model to support the new ways in which spatial information can be accessed. The aim of the research has been presented, along with a breakdown of the remaining chapters of this thesis.

The following chapter begins the background section of this research by describing the emerging field of LBS. Using the contributing components of position, information and communication, the history and evolution of LBS and some of the technicalities of LBS application deployment are explored.

Chapter 2 Location Based Services

Identified in Chapter 1 as an emerging class of applications, LBS are changing the way spatially related information is accessed and used.

This chapter introduces the background theory on LBS by focusing on the three convergent technology fields that enable them – position, information and communication. In turn, the history of each field is examined and the elements that facilitate the convergence with other fields to form the technological basis for LBS are identified.

2.1 Introduction

Around the world, wireless telecommunication carriers are committing enormous resources to building the communications infrastructure to make wireless services reliable and widely accessible (Ferguson 2000). LBS are consistently cited as one of the main applications that will enable the carriers to recoup their investments (Blonz & McCarthy 1998; Hayes 2000; McCabe 1999). Whilst they can take on many forms and provide value in many ways, all location services require spatial data handling capabilities to link location with other data sources. The management and dissemination of relevant information to mobile users requires technology that can be used to integrate information with the rapidly evolving Internet and communication standards (Koeppel 2002).

The spatial processing aspect of LBS relies on the functionality that is available in GIS, and as a result LBS have been regarded by some as specialised GIS with restructured interfaces; Niedzwiadek (2002) for example, discusses this philosophy. GIS spatial functionality has certainly spurred the development of LBS however as this chapter will explain, LBS are more than just specialised GIS applications for the mobile environment.

2.2 Background

The proliferation of mobile phones into society has led to a changing communication paradigm, described by some as a paradigm shift, in how information is accessed and utilised in a 'mobile centric' world (Sacher & Loudon 2002). Mobile phones have provided an unparalleled freedom to communicate in a variety of modes, irrespective of location (Solymar 1999; Singleton 1983; Cox 1996). In addition to voice calls, mobile phones offer text messaging capabilities (such as the Short Message Service (SMS)) and are increasingly offering Mobile or Wireless Internet access (e.g. via WAP) and multimedia messaging facilities (via the Multimedia Messaging Service (MMS)). Mobile phone functionality is also starting to be integrated with PDAs and positioning/presence technologies (such as the Global Positioning System (GPS) and Bluetooth®) (Koh & Kim 2000; Blonz & McCarthy 1998; Pratt 1999) allowing users to own and carry one device that is capable of recording and organising tasks, as well as communicating with others.

Predictions in the level of adoption, and the type of services offered abound (refer to Blonz & McCarthy 1998; McCabe 1999; Robinson 2000; Souissi & Phillips 2000; Dennis 2001). In 2000 and 2001 Ericsson (2000a; 2001) predicted that the number of Mobile Internet subscribers would outnumber fixed line Internet subscribers by 2003. Currently there are over 1 billion mobile phones in circulation world-wide (GSM Association 2003) however only a very small proportion of these are Mobile Internet enabled. In Australia less than 4% of mobile subscribers have Mobile Internet enabled phones (Australian Communications Authority 2001). Current and proposed services range from business support through to entertainment as shown in Figure 2-1, and many of these services have a location or spatial component (e.g. driving directions, traffic and driving updates, weather information, local services information, entertainment directories and theatre/movie ticket ordering). Collectively mobile communication technology is fundamentally changing how we manage our day to day activities (Carroll, Kellogg & Rosson 1991).

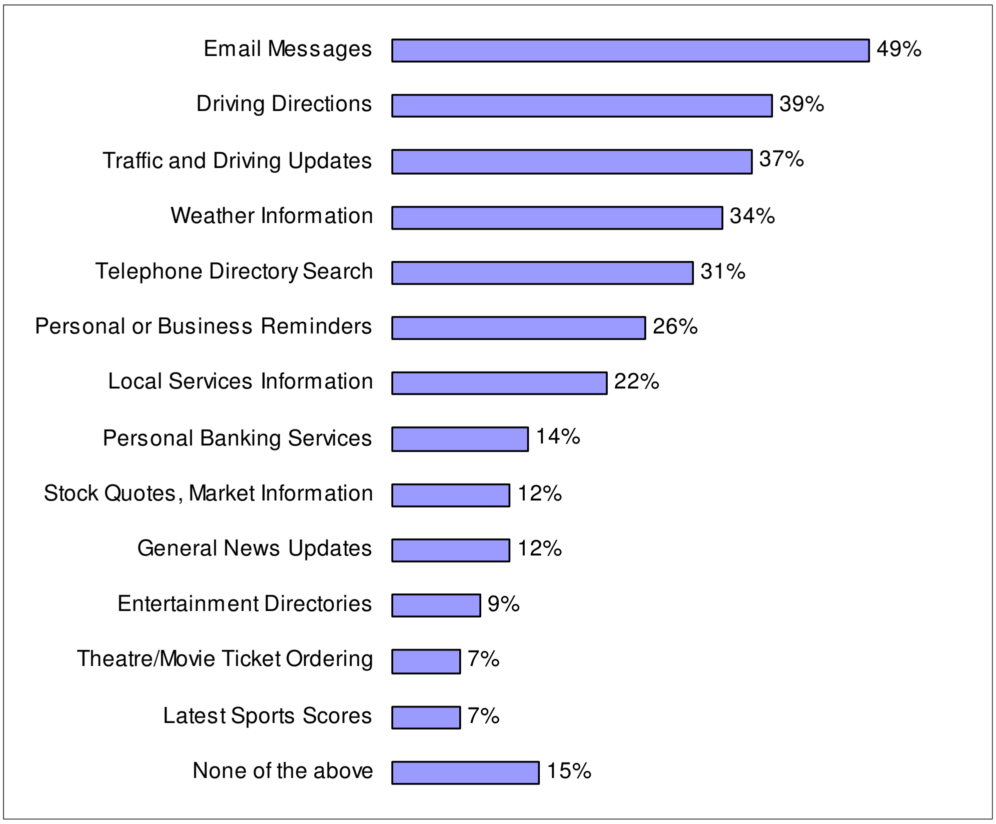


Figure 2-1 Mobile Internet application preference (Bourrie 2000 p.22A)

The delivery of services over mobile devices is a huge growth industry. Exceeding expectations (refer to Ericsson 2000a) mobile phone subscriptions outnumbered fixed line phone connections in Australia in 2001 (Australian Communications Authority 2001). With the rapid global uptake of mobile phones, the provision of position sensitive, time critical information to mobile users through a variety of devices is an emerging area and has been encouraged by legislative mandates in the USA and similar initiatives in Europe (refer to FCC 1999a; Parthus Technologies 2001 respectively). These sorts of services can all be classified as LBS. The following section provides a formal definition of the term.

2.2.1 Definition

Consensus on the use of the LBS term is difficult to come by, and as a result definitions for the term abound. This is probably a result of the nascence of the technologies and applications. Essentially LBS are distinguished from other services due to their use of position or location information. This can be in the form of utilising the user's position (determined either automatically or manually) in the service, or by the service returning some form of spatial information (including the location of some object). While not specifically restricted to services that are accessible via a mobile phone, LBS are typically thought of as services that operate within the wireless sector. From a very general perspective Lopez (2000 p.1) notes that 'Internet and wireless service providers are beginning to deliver web mapping, street routing and electronic yellow page services to both web and wireless handsets', however as Torrieri (2000) points out, it is the location services aspect that marks the wireless experience as unique. The distinction between the transmission medium (fixed wire or wireless), and the associated positioning or location component has led to definitions such as that proposed by Davies (2000b):

> *Location Services* deliver information about the geographic location of mobile telecommunications devices. This includes mobile telephones, mobile interactive browsers and devices attached to other moveable items such as people, packages and vehicles.
> *Location Based Services* deliver end-user applications based on Location Services.

LBS can include applications that enable emergency response dispatchers to identify accident sites and accurately dispatch vehicles to them; help a tourist plan a visit to a gallery (including an assessment of whether there is enough time for the visit and navigation information on how to get there); allow courier operators to monitor their fleet or consumers to track parcel deliveries; or enable stores to target advertisements to only those people within close proximity.

The distinction between Location Services and Location Based Services, as identified by Davies (2000b; 2000a), is not always made. Although the concept of LBS is not particularly new (especially given the similarities to research in the field of context awareness) (refer to Townsend 2001; Harter & Hopper 1994; Leonhardt & Maggee 1996), many contemporary definitions focus on current technology, on the devices used for human-service interaction and the communication network used to make the services accessible (refer to Table 2-1). However there are a few more broader and holistic definitions such as those by Java Location Services (2001) and the Open GIS Consortium (OGC) (Kottman 2000).

Table 2-1 Example LBS definitions

Definition	Source
Mobile location services are value-added services, which are dependent on information about the user's position on current networks.	(Blonz & McCarthy 1998 p.25)
Location based services – a set of new applications that utilise the geographic position of a mobile device.	(McCabe 1999 p.1)
Location Services deliver information about the geographic location of mobile telecommunications devices. This includes mobile telephones, mobile interactive browsers (i.e. WAP or I-Mode) and devices attached to other moveable items such as people, packages and vehicles. Location Based Services deliver end-user applications based on Location Services.	(Davies 2000a p.1)
Location based services allow mobile users to receive services based on their geographic location or position.	(Ericsson 2000b p.1)
A location based service is a software process that utilises the geophysical location of the mobile unit as part of its algorithm for generating presentation layer content.	(Gravitate Inc. 2000 p.1)
Location-based services are services that empower (single or collections of) devices (and users or enterprises with devices) to acquire and take advantage of their location or mobility, or to acquire and take advantage of the location or mobility of other devices or objects with devices. Here the term 'device' is sometimes replaced with more precise terms, such as 'client', 'server' or 'proxy'. An 'object with a device' is sometimes replaced with the more precise 'user', 'target' or 'OGC feature'.	(Kottman 2000 p.2)
Location services provide content information to the end user based on the geographic location of the mobile station (MS).	(Souissi & Phillips 2000 p.2)
A location-based service could be defined as an information service that exploits the ability of technology to know where it is, and to modify the information it presents accordingly.	(Golledge 2001 p.2)
Location services enable customised information to be delivered or made available based on the specific location of the user. Knowing where the user is at any given time adds a valuable dimension to the kinds of services that can be offered.	(Java Location Services 2001 p.1)
Location-based service (i.e. position-dependent service) means a service that can be found easily on the basis of its described location with the aid of different kinds of indexing and guidance services.	(Rainio 2001 p.2)
Location-based services deliver geographic information and geo-processing power to mobile and static users via the Internet and wireless network in accordance with [the] current location of [the] mobile user, or the hypothetical location of [a] stationary user.	(Stojanovic & Djordjevic-Kajan 2001 p.459)
LBS are applications, which re-act according to a geographic trigger.	(whereonearth 2001 WWW site)
LBS defines those mobile commerce services that utilise information about the current location of the person using a mobile device. Ideally the information provided should be both location-specific and personalised based on the personal profile of the user.	(MobileInfo.com 2002 WWW site)
A service, query or process that enables relevant information access in relation to the changing spatial relationships of targets over time.	(ISO/TC211 2003 p.20)

Examination of the definitions in Table 2-1 suggests that LBS reinforce geography and a sense of place to mobile users, and that they can also assist with the user's decision making process. Decision making may be broadly defined to include any choice or selection of alternative courses of action. Decision making that involves spatial data and information is referred to as spatial decision making, whereby the decision making process involves the analysis of spatial events and the results of the analysis (decisions) depend on the spatial arrangement of the events. The notion of spatial decision making and its relation to LBS is explored in more detail in the next section.

Combining the definitions and ideas of LBS, it is possible to propose that if a decision making process involves the use of a service based on spatial, time dependent data with respect to the position of the decision maker (and possibly the position of some target object), the service can be defined as an LBS.

In other words:

> An LBS is concerned with supporting dynamic spatial decision making through the provision of real-time, geographically based information.

This definition is extremely broad and does not restrict the communication media through which the service operates. For the purpose of this research, only wireless LBS have been considered. This focus has been based on the high proportion of ad hoc spatial decisions that are made on an everyday basis, and the fact that services to support this type of decision making are becoming more readily available to users via wireless telecommunication devices. As discussed further in Section 2.5.2 these devices fall under the category of handheld devices.

The decision making process referred to in the previous definition is from the perspective of an individual (rather than a group or organisation) concerned with coming to a decision involving location. The decision making process could involve deliberating over a means of transportation or a transportation route. Within this context, spatial decision making therefore refers to the process undertaken in coming to a decision that is related (in either the procedure or the final result) to a geographical or spatial entity (for example a place or location). The dynamic component relates to the changing environment or context in which the individual is operating. This change may be a function of time, the geographical position of the individual, or the tasks that the user is performing. For example, en route from A to B if a traveller decides to stop at a point C, they should be able to use the LBS to alter their current route, to include the new change. Similarly, if being guided by navigation directions from A to B and a wrong turn is made, they should be able to use the LBS to obtain new directions (ideally sophisticated LBS should automatically detect and deal with this case). The flexible and adaptive decision making process of individuals (Payne, Bettman & Johnson 1993), in conjunction with an often changing and complex task environment demands significant support, which to some degree can be provided by LBS via wireless electronic devices.

In summary, LBS are a result of the convergence of position, information and communication technologies as shown in Figure 2-2, and encompass issues of human-computer interaction (modes of interaction and immersion, decision making and activity scheduling), data (metadata, standards, scale, multi-modal delivery and dynamic updates), spatial analysis (topological modelling, information trawling, integration and conflation, and abstraction and generalisation), people (personalisation, computer literacy, spatial literacy, social or cultural influences) and applications (revenue models, policy, privacy, role of value added resellers). Whilst each of these is individually worthy of pursuit, the philosophical underpinning of this research relies on the relationship and interdependencies between the components. For example, delivering a dynamic routing map relies on an interdependence between network capacity and the display device for the rendering of the map. The delivery of LBS must model the interdependencies that exist between a (set of) position(s), the information relevant to those positions, and the communication necessary to support the flow of information to the user.

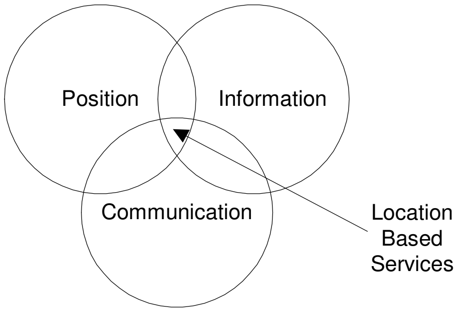


Figure 2-2 LBS – the convergence of technologies

The technology convergence has resulted in four categories within the LBS provision or development environment. Figure 2-3 depicts these components as location providers (position), platform developers (communication), application developers (predominantly communication, but could encompass all three technologies) and content providers (information).

Category	*Description*	*Example Organisations*
Application Developers	Develop LBS applications	SignalSoft Ericsson MPC Webraska
Platform Developers	Middleware connecting infrastructure systems to the applications and location provider	LocatioNet Ericsson Webraska
Location Providers	Use location technologies to determine positions of mobile devices	Cambridge Positioning SnapTrak CellPoint
Content Providers	Complete the offering of the application developer, by providing data	TeleAtlas GDT Sensis

Figure 2-3 LBS structure (adapted from Amit 2000)

At the lowest level are the content providers who capture and maintain relevant content for LBS. Location providers and positioning technology vendors, at the next level, offer solutions for accurately determining the position of an LBS user. Typically, in wireless LBS this is achieved through determining the position of the service user's handheld device (methods for positioning are detailed in Section 2.3). The position information needs to be integrated with the communication networks to provide access to the service. Platform developers take on this role and can be regarded as the necessary middleware or distribution gateway connecting applications with the communication channel. Organisations undertaking this responsibility often develop an Application Programming Interface (API) access to their services facilitating application development by third parties. Application developers produce the LBS applications for service users. They require content (supplied by content providers), a location for the service user (provided as part of the application or from the location provider through the platform developer) and a means to make the application accessible (provided by platform developers). Together these components result in LBS applications that service users can interact with in order to make decisions. The category breakdown demonstrates the abstraction of the position, information and communication components of LBS. It is this abstraction that provides flexibility allowing LBS to be implemented today with existing technology, while remaining open to additional technologies as, and when, they mature. It should be noted that these categories are not mutually exclusive from the perspective of an organisation and it is possible for the one organisation to take on several of the roles described above (for example, as shown in Figure 2-3 Webraska Mobile Technologies SA (Webraska™) a leading provider of integrated LBS, telematics, navigation and mobile enterprise solutions covers both the application developer and platform developer categories).

The following section offers further background on spatial decision making and its applicability to LBS applications before each of the technology components is investigated in more detail.

2.2.2 Spatial Decision Making

The process of making a decision or choosing one alternative from many possibilities occurs at a variety of levels and with many varying intents. Simon (1977), Faludi (1973), Lee (1973), and Chadwick (1978) suggest that decision making is a process of choice, action and learning. Choices are made based on knowledge of the world and of oneself (referred to as 'image'), which is continually modified by activities engendered by choices (Mulolwa 2002). Often many of the decisions made as a part of everyday activity relate to places or locations; 'people make decisions influenced by geography when they choose a store to shop, a route to drive, a path to jog, or a neighbourhood for a place to live' (Jankowski & Nyerges 2001 p.1). Mulolwa (2002) argues that the knowledge upon which decisions are made is contextual in terms of data collection practices, analysis purposes and assumptions, and therefore has implications for the decision making process. The physical definition of context that is utilised by, and often inherently associated with LBS, can also have a strong impact on spatial decision making (Graham & Kjeldskov 2003; Kjeldskov 2002; Krishnan n.d.; Pradhan 2002).

Spatial decision making can range from simple queries (where decisions can be extracted by querying GIS databases) through to more complex queries relying on interactive and iterative evaluation and interpretation (Jankowski & Nyerges 2001). When examining the number of participants and the effect of the decision, or the decision equity, LBS typically fall at the lower level of the spatial decision making scale (refer to Figure 2-4) usually assisting with ad hoc spatial queries made by individuals or small groups of people with common interests.

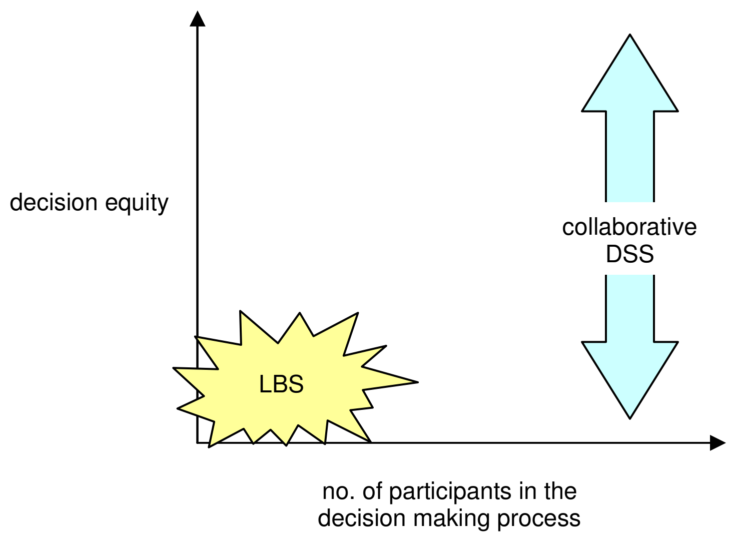


Figure 2-4 LBS on a decision support scale

Forming probably the largest group of spatial decisions are those of an ad hoc nature that require little structured or formal analysis (Jankowski & Nyerges 2001). Jankowski and Nyerges (2001) also propose that individual spatial decisions are often based on experiential heuristics and individual preferences as a consequence of the small ‘decision equity’ that is at stake. A poor decision could result in the individual experiencing a less than optimal solution. For example, this could be in the form of paying a higher price for an item, being presented with a limited range of stock or experiencing longer travel times. While not particularly devastating, the result of such choices contributes to the decision maker's preferences and experiences and implicitly forms experiential heuristics which can be called upon when making future decisions.

The more formal subset of spatial decision making, related to activities such as site selection, resources dispatch or environmental monitoring, typically involve participants as representatives of stakeholder groups, decision makers or technical specialists. It is this specialised group for which decision support theories and practices have traditionally been adopted and developed. These theories are increasingly considering collaborative decision making in recognition of the fact that in this category, decisions are rarely made by a single individual. Despite this difference, there are some commonalities between these and the less structured spatial decision making forms. In both cases it is highly likely that there will be a wide range of spatial expertise of the participants. In the example case of a site selection for a new freeway, stakeholder groups could include local governments, environment protection groups and traffic authorities, whose individual representatives may not have been trained beyond high school level in geography or the spatial sciences. It is likely that the average mobile phone owner will be in a similar situation. However all of these people are interested in obtaining information that involves location. McKee (2000) notes the trends in improving access, acquisition, management, update and distribution of spatial data may mean that the need for specific spatial expertise for decision making in these areas will be reduced. However McKee goes on to suggest that specialist businesses that facilitate collaborative spatial decision making will develop, while spatial applications to support everyday activities will become increasingly commonplace; 'the mundane and the professional will overlap and mix in unpredictable ways' (McKee 2000 p.19).

Additionally, the driving force behind collaborative decision support systems is to reduce the cognitive load imposed on the decision makers. As explained by Jankowski (2001), this should allow for a more thorough treatment of information and result in more equitable participatory decisions. This intent should be paralleled by LBS, by aiming to reduce the complexity of everyday spatial decision making tasks and minimising the cognitive load on individual mobile users as they are undertaken.

The ‘service’ notion of LBS can assist in this regard; each service helps users to answer task specific location related questions (for example, ‘how do I get from A to B using public transport?’). While each LBS is a (simple) form of a spatial decision support system, linking services together to form a more rigorous decision support system, as shown in Figure 2-5, could help to significantly reduce cognitive load associated with everyday spatial decision making tasks. A fully developed spatial decision support system of this form would be able to provide solutions for more generic queries (for example, ‘what’s the best way to get to C?’) by connecting to individual LBS in order to complete each particular phase of the query. For the example query of ‘what’s the best way to get to C?’, this type of model should be able to evaluate transport alternatives, taking into account user preferences, time constraints, weather conditions etc., to come up with an optimal solution tailored specifically for the decision maker.

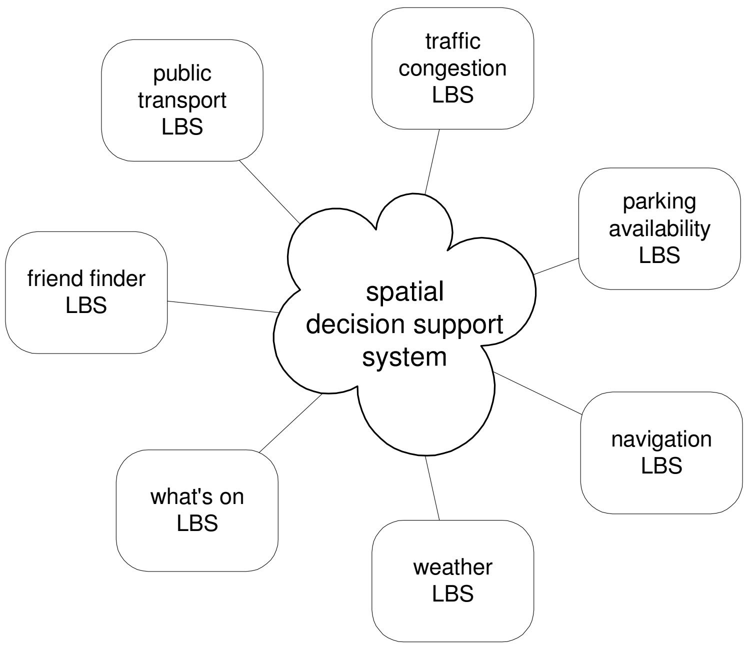


Figure 2-5 A model for a spatial decision support system for everyday tasks

To achieve the model described above and shown in Figure 2-5, each of the LBS could be a series of software agents that cooperate to enable the spatial decision support system.

Agent Theory

As a way in which to handle some of the complexity of decision making computationally, artificial intelligence research has developed the notion of agents – autonomous, cooperating computational processes (Adler & Cottman 1989). Explained by Lieberman and Selker (2000), agents attempt to simulate the properties of human decision making: learning from past experience, gaining information from context and combining partial information that comes from different sources at different times; with the ultimate aim of understanding the intent of a human user.

Context and space play an important role in assisting an agent to solve a problem, and remains an active research focus in the artificial intelligence field. In the spatial information field, Rodrigues and Raper (1999) have identified a number of specific areas which could benefit from spatial agents – task oriented agents, focused on solving problems related to spatial data handling, or to solve problems with spatial goals. They propose that spatial agents could assist with spatial data mining, help to improve GIS interfaces, facilitate spatial tasks and improve the connection of spatial systems (Rodrigues & Raper 1999). These areas are all relevant to LBS.

As suggested by Cabri et al. (forthcoming) processing will increasingly be delegated to autonomous software agents, partially due to their ability to adapt well to the physical and logical location changes of mobile users. Indeed multiagent systems (Jennings 2001), where an agent does not act alone, but works together and in coordination with other agents may be necessary for sophisticated LBS.

Identified previously, LBS rely on a combination of position, information and communication components in order to provide decision making support. The following sections review each of these components in turn.

2.3 Position

Critical to many LBS is position determination of the service user. Position determination is one mechanism for providing customised and relevant content to users. Determining the position of a user (or more specifically their handheld device) can be achieved using numerous technologies. Existing LBS implementations have embraced current technologies while maintaining adaptability for future developments by abstracting positioning techniques from the LBS application (as shown in Figure 2-3).

In the wireless environment where users are highly mobile, determining and monitoring their position can be a difficult and complex task depending on the desired accuracy and frequency of position recording. Much research has been undertaken on methods of determining the position of mobile devices (Leonhardt & Maggee 1996; Hodes & Katz 1997; Smyth 2000) and mobile phones in particular (ETSI 2000; Hayes 2000; Drane & Rizos 1998). These techniques are examined in the following sections.

2.3.1 Mobile Device Positioning

In the wireless environment, location or position is often described as the essence of mobility; however mobility offers many challenges to the computing and communications areas. One challenge, which has been under investigation within the computer science field for some time, relates to determining the position and context of mobile users.

From a technical perspective, positioning techniques for devices have typically involved adapting existing positioning methods so that they may be compatible with handheld devices. The most prevalent example is that of GPS receivers. With increasing awareness of GPS and decreasing receiver sizes and manufacturing costs, GPS receivers are permitting position determination to be a ubiquitous quantity (Bryant, Dougan & Glennon 2001; Richardson 2001; Specter 2000). GPS receivers have been manufactured to support laptop and field computer use, as well as the major handheld computing brands. Manufacturers have also embraced Bluetooth technology, and this is now an affordable and easy way to 'position-enable' handheld devices (e.g. using a Bluetooth GPS receiver with a Bluetooth PDA requires no cables or physical connection between the two objects). Specialised beacon systems have also been developed and used for over a decade by PARC™, Olivetti and similar organisations in their studies on positioning and context awareness (Want et al. 1992; Beadle et al. 1997; Hodes & Katz 1997; Harter & Hopper 1994), however the need to install and set up a dedicated system for positioning has somewhat hindered the adoption of these technologies.

While technological advances in satellite navigation, inertial technology and integrated systems have almost overcome the challenges in pinpointing user positions to a high degree of accuracy, the challenge of determining context remains – despite the research that has been completed on context sensitive applications or information access based on location (Imielinski & Viswanathan 1994; Leonhardt & Maggee 1996; Hodes & Katz 1997; Couderc & Kermarrec 1999; José & Davies 1999; Kristoffersen & Ljungberg 1999; Smyth 2000). One of the difficulties in this regard is the Internet's lack of conceptual models supporting the association between information and position or location.

Context can be defined in many ways. Couderc and Kermarrec (1999) use two definitions. Firstly context may be defined in terms of the physical location of the mobile device in space, and secondly in terms of the type of mobile device (e.g. laptop computer, web enabled phone or PDA). The need for applications to adapt to both of these definitions of context is important and thus content that is presented to mobile users must be scalable. While LBS will typically be accessed from handheld devices such as PDAs, mobile phones or combined communicator devices (e.g. smart phones, refer to Section 2.5.2), this issue of adaptability is extremely important given the lack of standardisation of operating systems, interfaces and software across this range of devices. These type of features need to be considered if an efficient communications, and accessible and interoperable spatial infrastructure is to be established.

Recently, research interests into positioning and context determination have focused on mobile phones (Drane & Rizos 1998; ETSI 2000; Hayes 2000) in response to initiatives aimed at improving the assistance provided to emergency callers. In particular the US and Europe have developed legislative mandates for the location determination of callers dialling the national emergency number. The US Enhanced 911 (E911) mandate, under the Federal Communications Commission (FCC), aims to 'improve the reliability of wireless 911 services and to provide the enhanced features generally available for wireline calls' (FCC 1999a) has been one of the driving forces in this regard. Implemented in two phases, the first phase of the mandate requires that telephone number and rough location (based on the location of the antenna that received the call) of the caller be provided to the emergency service contact (FCC 1999b). The second phase requires more precise location information with callers to be located to an accuracy of 50 to 100 metres 67% of the time depending on the form of positioning (FCC 1999b). A four year rollout plan (from the 1st of October 2001 until the 31st of December 2005) has been adopted by the FCC for E911 Phase II compliance (FCC 2003).

Europe and Australia are following the US with the Commission of the European Communities passing a recommendation on the processing of caller location information in electronic communication networks for the purpose of location-enhanced emergency call services (Europa 2003) and the Australian Communications Authority releasing a discussion paper requesting views from stakeholders and interested parties on location information techniques for emergency calls (Australian Communications Authority 2004).

2.3.2 Mobile Phone Positioning

Mobile phone positioning techniques are typically grouped according to whether the position calculation takes place at the handset or within the phone network. *Handset based* positioning systems describe those where the positioning intelligence is stored in the mobile handset or on its Subscriber Identity Module (SIM) card. The fundamental information required to locate the handset is measured at the handset itself, with the network playing only a minor role. *Network based* positioning systems rely heavily on the network infrastructure, and monitor handset signals within the network Unlike handset based positioning, these systems do not require subscribers to purchase new equipment (such as a handset or SIM card) in order to

use the positioning capabilities, however they are typically less accurate.
The European Telecommunications Standards Institute (ETSI) and T1P1 committee (a subcommittee of T1, a US telecommunications standards committee, concerned with wireless/mobile services and systems) have decided on the standardisation of three mobile phone positioning systems:

- Enhanced Observed Time Difference (E-OTD) (handset based)
- Time of Arrival (TOA) (network based)
- Assisted Global Positioning System (A-GPS) (handset based)

(ETSI 2000)

These systems each offer improved positioning accuracy when compared to the standard Cell of Origin positioning technique inherent in all cellular mobile phone networks (refer to Table 2-2).

Table 2-2 Positioning system accuracy (adapted from Swedberg 1999)

Positioning System	Accuracy (m)
EOTD	60 – 200
TOA	50 – 150
A-GPS	10 – 20
Cell of Origin	100 – 3000

The following sections describe the Cell of Origin and standardised mobile (cellular) phone positioning systems in more detail.

Network based positioning

Each mobile phone network has an inbuilt positioning capability which is used to keep track of the position of mobile phones within the network so that calls may be placed successfully through to the appropriate mobile subscriber. In the case of cellular networks (such as the Global System for Mobile Communication (GSM)) this system is known as Cell of Origin. Even though this system operates for all mobile phones without handset or network modifications, the accuracy of this positioning system is dependent on the coverage area of the base station. Base stations are located in order to accommodate expected communication usage patterns, rather than for geometric positioning, and as a result only limited positioning accuracy can be achieved using this technique (approximately 100m in urban centres and up to 3000m in rural areas). There are other network based positioning systems that offer improved positioning accuracies when compared with the Cell of Origin technique, that are based on timing signal speeds.

The TOA method measures the time of arrival of a signal from a mobile terminal to three or more base stations. The signal burst from a mobile terminal radiates equally in all directions at a constant speed. Location Measurement Units at the base stations receive the bursts and measure the value of the uplink time of arrival. A circle, of radius equal to the distance travelled by the signal in the measured time, can be drawn from each base station. The intersection point of the circles from three base stations uniquely determines the position of the mobile phone (refer to Figure 2-6). Retscher (2001 p.4) indicates that in the case of redundant observations (e.g. solutions involving four or more base stations), ‘the position fix together with the time offset and error of the clock of the mobile station (MS) is estimated using a least-squares adjustment’.

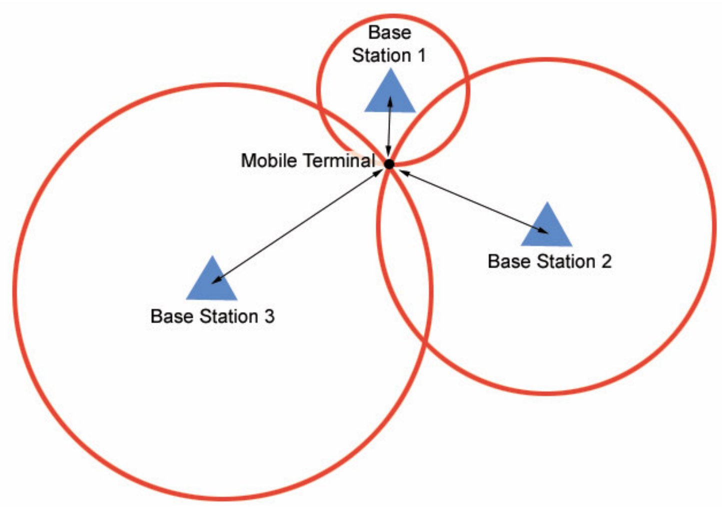


Figure 2-6 Time of Arrival positioning

This method does not require any modification to existing handsets, but network modification is required. Accuracy typically varies between 50 and 150 metres (Swedberg 1999).

While LBS applications have been successfully deployed using Cell of Origin positioning, determining a user's position more precisely can assist in providing highly relevant and specific information. Handset positioning techniques typically offer greater precision, but require specialised hardware.

Handset based positioning

The E-OTD method is based on measurements at the mobile terminal of observed time differences between pairs of local base transceiver stations. Since transmissions from base stations are not synchronised, the network must measure the relative time difference between the transmissions. For any particular pair of stations, the time difference is related to the difference in distance from the mobile terminal to the two stations. A hyperbolic line of constant distance difference can be drawn for three station pairs. The intersection of the hyperbolae is the position of the mobile phone (refer to Figure 2-7). This can be calculated at the mobile terminal (if all of the information is available) or in the network. This method is capable of positioning a mobile phone with an accuracy of 60 to 200 metres and requires both network and handset modifications (Swedberg 1999).

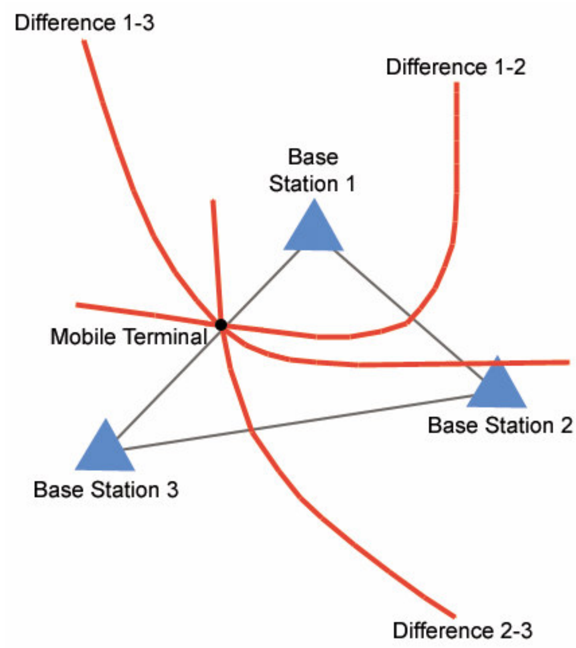


Figure 2-7 Enhanced Observed Time Difference positioning technique

The most accurate of the standardised methods, A-GPS relies on the GSM network providing additional information to provide integrated GPS receivers with improved coverage compared to stand-alone receivers (Zhao 2000). Figure 2-8 depicts A-GPS positioning with a GPS receiver embedded in a mobile phone. Since stand alone GPS positioning is subject to errors (commonly classified as: ephemeris data, satellite clock, ionosphere, troposphere, multipath and receiver errors), the additional observations provided by an A-GPS system help to improve the reliability and accuracy of positioning. Different kinds of location measurement units can be used to collect the data to assist the positioning solution (refer to Table 2-3). For example, in order to provide satellite ephemeris and differential GPS correction, one measurement unit must be deployed approximately every 300km in the network. This configuration provides accuracies to within 10 or 20 metres (Swedberg 1999). The achievable accuracies of A-GPS are a subject of ongoing research; field studies report a range of achievable accuracies from 5 – 50m (SnapTrack 2002) to 43 – 250m (Cambridge Positioning Systems 2003) depending on the context of the user. To further increase GPS coverage, a highly accurate time reference needs to be provided and could be achieved through the deployment of one measurement unit in every third base station.

Table 2-3 GSM network assistance for Assisted GPS (Swedberg 1999 p.216)

Type of Assistance	Benefit
Satellite ephemeris	Improves time-to-fix or sensitivity, or both, by focusing acquisition. Improves time-to-fix by eliminating the need to demodulate navigation messages.
Frequency accuracy	Improves time-to-fix by focusing acquisition.
Location estimate	Initialises the position computation procedure. Improves the acquisition of second and subsequent signals.
Differential GPS correction	Improves the accuracy of position estimates (10-20m).
Time reference	Improves time-to-fix for all receivers. Improves sensitivity for receivers in poor signal environments.

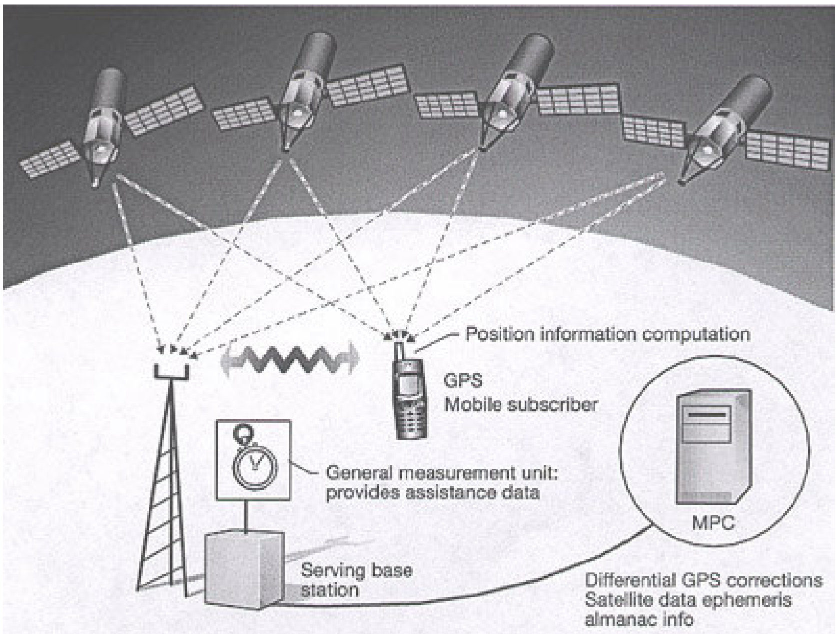


Figure 2-8 Assisted GPS positioning (Swedberg 1999 p.216)

The accuracy of the position fix for the systems described above, as is also the case with other positioning systems, is dependent on the number of measurements and their geometric configuration. Retscher (2001) identifies that the geometric configuration is the limiting factor for these technologies due to the fact that base stations are generally located to provide adequate coverage for communication rather than to assist with position determination. Additionally, priority on the GSM network is assigned for communication services, thus only a limited number of users can perform location determination at any one time. Multipath (the propagation phenomenon that results in radio signals reaching a receiving antenna via two or more paths) also plays a major role in limiting position accuracies in network-based positioning techniques.

The ability to reference a user's position to other pertinent information as described by Koeppel (2002) adds both meaning and value to the position information. The following section examines the second contributing technology area for LBS – information.

2.4 Information

While position can be recorded and documented using coordinate reference systems as described in the previous section, the ability to link it to other spatial and non-spatial information adds significant value. The terms *position* and *location* are often used interchangeably, however for clarity throughout this thesis they have been defined as follows:

Position typically refers to the coordinates (in a given coordinate system) that represent a place on the Earth. However Kottman (2000) notes that the semantics of this term vary depending on the application domain. Positions are typically examples of point geometry.

Location is an identifiable place in the real world, and can be composed of position coordinates in conjunction with other spatial and non-spatial attribute information. Location can be an address from an address system, a description or name, postcode, phone number or even a landmark or event. Locations can be represented by points, lines, polygons or more complex geometries and are often inexact, scale- or context-dependent.

Both position and location can have varying degrees of uncertainty between the representation and the actual place that they refer to and thus must be dealt with appropriately.

As an information based society, Koeppel (2002 p.1) notes that 'we value systems and services that tell us about the location of objects'. This has been reflected in the spatial industry over the last decade where the focus has been on data generation and collation (Phillips, Williamson & Ezigbalike 1999). As a result, existing information systems contain many databases linked to location or geographic components (Koeppel 2002).

In some respects, spatial databases and geographical information systems have typically been isolated from mainstream information systems due to the complexities and limitations of the technology to manipulate spatial data. Increasingly, position and location are being seen as ‘ubiquitous information ingredients’ (Niedzwiadek 2002 p.2), and thus the incorporation of spatial information into the general information infrastructure has begun in earnest (McKee 2000). In turn, LBS should be an extension of the information infrastructure, and facilitate access to spatial information resources.

Location can be regarded as a ‘foundational property’ (Niedzwiadek 2002 p.2) for modelling the world in an intuitive way given that it is a universal property that people use to understand and relate to their surroundings. Niedzwiadek (2002 p.2) goes on to suggest that location can be exploited ‘as a unifying information theme to better understand the context of most real and abstract phenomena’ and LBS represent one way in which this is already beginning to be achieved.

Recognised by organisations such as the OGC, the importance of linking a position with spatial and attribute information and making it available in a variety of forms has led to the instigation of initiatives such as the Open Location Services (OpenLS). This group is specifically tasked with capitalising on the importance of spatial information systems and the necessary infrastructure required to make them accessible via mobile devices:

> Spatial connectivity is a primary, universal construct for business planning and modelling, service development and deployment, network provisioning and operation and customer satisfaction. Location application services are of universal industry significance and depend upon the availability of relevant spatial information infrastructures in forms useful for small devices.
> (Open GIS Consortium 2000)

Associated with the increased accessibility of spatial information is an increase in the user base of spatial information products and services. Spatial information that is accessible in general information infrastructures will have to cater for users with a range of spatial abilities accessing the services using a variety of hardware products. The domains over which the benefits of accessing spatial information are likely to extend are unknown, but McKee (2000 p.14) predicts that special training will not be required for the majority of beneficiaries. Spatial services and applications will slowly seep into everyday use, assisting people in their day to day tasks.

Underlying the applications and services, large repositories are required to efficiently store and manage the contributing information. The Internet can be regarded as a comprehensive information repository with the World Wide Web (WWW) and the File Transfer Protocol (FTP) as examples of information access or dissemination mechanisms. Over the past two decades the Internet, and in particular the WWW, has had a major impact on the business and social sectors of our society. It has provided new ways to communicate, distribute and access information. In the Geomatics industry, the Internet has facilitated the dissemination of spatial information to a wide audience. Online GIS, visualisations, image viewers and cadastral or land information services have all contributed to an increased number of spatial information users. The following sections describe some of the information resources and strategies, that are providing the information component of LBS.

2.4.1 The World Wide Web

The WWW was conceived by Tim Berners-Lee whilst working at the European Organization for Nuclear Research (CERN) to provide a common information space where information could be shared (Berners-Lee & Fischetti 1999). Based on the client-server architecture (refer to 3.6.2), users (on the client side) are presented with a wide range of web pages that are interconnected by hyperlinks. Client machines with Web browsers can connect directly to the Internet, or through a PPP (Point to Point Protocol) connection with an Internet Service Provider (ISP). Browsers on client machines establish TCP (Transmission Control Protocol) connections with web servers in order to access pages stored or hosted on the servers. The Web servers listen to Hypertext Transfer Protocol (HTTP) requests from clients (browsers). Web pages are uniquely defined and accessed by a Uniform Resource Locator (URL) which are composed of three sections: the protocol name (http), the host name where the page resides (www.unimelb.edu.au), and the name of the hypertext document (index.htm).

The WWW can be regarded as having revolutionised the dissemination of information (Green & Bossomaier 2002). With the exception of security based information systems, publishing information online enables it to be accessed by anyone, anywhere with access to a computer. As noted Green and Bossomaier (2002) this has simplified and expedited information access, and increased the quantity of information that can potentially be obtained by users. On the opposite side, organisations can provide wider access to information resources without the need for specialised hardware and software.

Not only does the WWW improve access to information, it also provides a unique opportunity in the ability to seamlessly merge distributed information. The data sharing and cooperation that this allows has previously been impossible on the scale that is now permitted by the Web (Green & Bossomaier 2002). For the spatial information industry in particular, the WWW offers several advantages in allowing for the distribution and access of datasets and spatial products online. Most prominently, the increased awareness of information resources will help to minimise the duplication of resources that has been a problem for the industry for some time. The potential to distribute processing and allow for remote data updating will also revolutionise the industry.

Additionally, the ability to distribute processing and allow users to access and use GIS on demand will enable a wide range of users who previously could not afford the specialised equipment and software required for spatial processing tasks. Subscription and pay-per-use business models will add a new dimension of flexibility to the industry; enhancing awareness and access to spatial information products (Green & Bossomaier 2002). While the WWW and the Internet provide the technical infrastructure to achieve collaboration, cooperation and sharing of data, the business rules (including protocols, standards for data recording, quality assurance, custodianship, copyright, legal liability and indexing) necessary to achieve this environment in practice still remain undefined. Green and Bossomaier (2002) suggest that overcoming the confusion that the Internet has achieved to date and resolving issues will require a balance of self-interest and cooperation between organisations. Initiatives such as the SDI can only assist in this regard.

Despite the Internet largely disregarding location and thereby enhancing location anonymity, Niedzwiadek (2002) suggests that location is an ideal theme by which to organise and embed greater intelligence in the Web. Using location as a 'foundational theme' will encourage value-add content providers and information brokers to contribute to the usual suppliers of fundamental location information. While value-add content providers will integrate location information with many other information sources, information brokers (acting as a mediator between content and service providers) will ensure that their clients have the best available information for their tasks (refer to Figure 2-9). As the complexity of the Web landscape increases, the role of information brokers will become increasingly more important (Niedzwiadek 2002). Once initiatives such as the semantic Web and OGC interfaces are commonplace, the role of information brokers may be minimised with the automation of processes to determine the appropriateness of information for particular purposes.

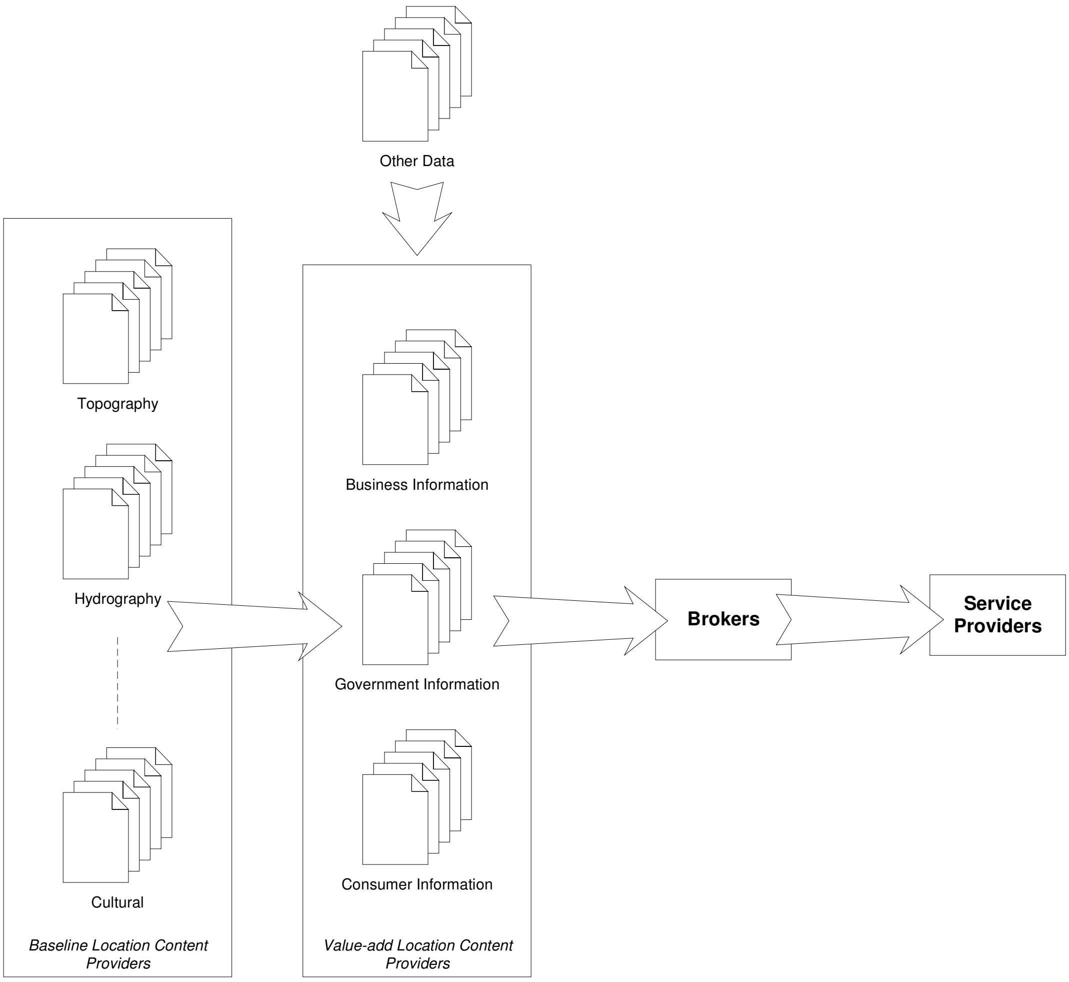


Figure 2-9 Location information value chain (Niedzwiadek 2002 p.3)

2.4.2 The Semantic Web

The next generation of the WWW, which is intended to add meaning and understanding to Web information and services, is referred to as the Semantic Web (Decker & Sintek 2003; World Wide Web Consortium 2003; Berners-Lee, Hendler & Lassila 2001). Increasing the level of integrated information intelligence and sophistication will enhance the potential for information automation, and as a result improved service levels for users. Niedzwiadek (2002 p.1) identifies that it is 'not semantics alone that provide value', with the technology to handle semantics being critical if service levels are to be improved and automation achieved.

Currently Web information is relatively limited in intelligence and additional semantics, so information directories (known as clearinghouses) have been developed to promote information resources and access mechanisms.

2.4.3 Clearinghouses

Spatial clearinghouses are typically systems of software and institutions that facilitate the discovery, evaluation, and downloading of digital spatial data. Clearinghouses are often implemented as either central data repositories or a set of interconnected web sites that reference spatial data; the US Federal Geographic Data Committee's (FGDC) Clearinghouse initiative is a 'distributed, electronically connected network of geospatial data producers, managers and users' (FGDC 2003) and therefore an example of the latter.

Like the Web itself, clearinghouses employ a client-server architecture; server machines hold the metadata (i.e. data about the content, quality, condition, and access methods) and users request information about the availability of data via Web browsers on client machines. Ideally, and as technology improves, clearinghouses will provide direct links to the data resources; at the moment few clearinghouses offer this facility and instead only connect to metadata repositories.

2.5 Communication

By its very nature, the Internet has evolved to remove the physical geographic location focus of its users. People from around the world can communicate, collaborate and share information almost as if they were in the same room. However, the availability of pervasive networking and affordable, powerful computing and communications platforms now offer, as described by Leiner et al. (2000 WWW site), 'a new paradigm of nomadic computing and communications'. This nomadic nature reverses the Internet's focus of geographic anonymity, with location now being an important factor. The intrinsic link between location and mobile communications means that location can now play an important role in the access and dissemination of information as has been identified in the previous sections.

Wireless communication methods are facilitating information access on a range of handheld devices. In today's society, wireless communication is often taken for granted, along with pervasive technology and equipment for reaching either large audiences (e.g. radio) or a single individual (e.g. mobile phone). This section goes on to describe the history of wireless communication, focusing specifically on technology developments to support the mobile phone and goes on to describe the range of devices that are becoming commonplace for data and voice mobile communication.

2.5.1 Wireless Communication History

Wireless communication has come a long way since its almost accidental discovery in association with fixed wire telegraphy, to support the mobile phones of today. In the broadest sense, a wireless communication system is designed to transmit waveforms (electrical signals) carrying information to a receiver (Couch 2001). Communication can be one-way, in the case of radio broadcasts, or two-way, for walkie-talkies or mobile phones. Essentially there are three methods by which wireless communication can occur: induction, conduction or radiation.

Induction is the principle describing the occurrence of an electrical current in a wire in response to a magnetic field. Communication via induction was discovered during wireline telegraphy (i.e. Morse code transmissions) experiments, when it was observed that parallel wires often induced currents in nearby wires, causing information to be confused and transmitted incorrectly. This was the first recognition that communication could occur without wires.

Wireless communication via conduction was observed for the first time in 1842 following a demonstration by Morse which aimed to show how electrical signals could travel through wires both in the air and underwater. During the demonstration, communication was disrupted when a ship inadvertently picked up the under water cable in the process of raising its anchor. To eliminate further problems of this nature, Morse resolved to arrange ‘wires along the banks of the river as to cause the water itself to conduct the electricity across’ (Hawks 1941 WWW site p. 3). A few months later, he did just this, and successfully demonstrated the first wireless telegraph.

Although induction and conduction can both be used to transmit electrical signals, they are limited in range, difficult to implement and cannot reliably and predictably be used to communicate over long distances. Radiation techniques (in the form of high frequency, rapidly moving waves generated by electricity and emitted from a fixed point like an antenna) overcome these limitations.

The third form of wireless communication was again discovered by pursuing unusual characteristics of another form of communication. David Hughes (an inventor credited with the invention of the microphone, which made the telephone a practicality) deduced that electromagnetic radiated emissions were emanating from his home built telephone. Further experiments followed and involved the construction of many pieces of equipment, one such piece allowed him to walk the streets of London with his telephone listening for ‘ticks’ from a clockwork transmitter at his home. Although it was only an electrical signal (not voice) and the signal was only one way, it was travelling in the radio frequency band (9kHz to 2000MHz – Australian digital mobile phones of today operate at 900MHz). Farley (2001) suggests that given the conditions of mobility, and use of the electromagnetic spectrum, Hughes can be regarded as receiving the first mobile telephone call in 1879.

The first radio telephone call that carried voice is attributed to Alexander Graham Bell in 1880. Bell experimented with a device known as the photophone which used a light beam to transmit voice (Grosvenor & Wesson 1997). This device was limited in practice (due to its reliance on a direct line of sight for communication and good weather conditions) but was a successful demonstration of the use of radiated electromagnetic waves to carry human voice.

Following these early developments, much experimentation and research has refined wireless communication techniques and practices. Technological advancements have enabled telephone exchanges to operate automatically (without the need for human intervention), frequencies to be reused (enabling many people access to wireless telephone communication), signals to be transmitted digitally rather than in analogue form (offering improved service, clarity of call and the capacity for more subscribers) and devices to be personally portable (as opposed to fixed on ships or in cars refer to Figure 2-10).

Figure 2-10 The first version of a mobile radio telephone (1924) (Lucent Technologies 2002 WWW site)

Today it is taken for granted that mobile phones can be used to communicate with others as and when needed. It is also increasingly possible to use mobile phones for data purposes – to send messages, access the Internet, check email, news, weather and stock price updates. The mobile or wireless Web is immersed in strong publicity from telecommunications networks and mobile handset manufacturers and whilst it is possible to access (albeit a limited range of) information on the wireless Web, the browsing experience is dramatically different to that of the more familiar desktop PC (as detailed in Section 2.5.3). The powerful processors, large colour screens and fast Internet connections common for desktop Internet connections have resulted in high expectations for information access speed and the types of media available. The wireless Web currently cannot compete with these expectations due to the wireless network infrastructure (often limited in bandwidth to a minimum of 9.6kbps, compared to a minimum of 56kbps for a fixed line dialup modem or 640kbps for cable modems (Weiss 2002)) and the devices used for access. However, accommodating for the unique features and limitations of wireless communication will help to advance the mobile Internet (Wireless Developer Network 2002).

One of the biggest advantages of wireless communication with mobile phones is freedom of use. They can be used outdoors and whilst physically moving around (that is, whilst mobile). Even in an indoors environment, the flexibility provided by a mobile device that can be kept by your side, 'ready to use', has been seen in the popularity of cordless telephone handsets. Whenever a mobile device is used for communication, the communication will originate from a specific location. This location 'variable' is a unique feature of wireless communication and, as explained in Section 2.3.2, has emerged as a significant one. The following sections describe the range of wireless communication devices, and the unique characteristics of information access using these devices.

2.5.2 Wireless Communication Devices

A range of devices can be used today to communicate wirelessly. Often referred to as handheld or portable devices, this category forms one subset within the larger consumer electronic device set which includes devices such as portable games consoles, cameras, calculators and MP3 players. Weiss (2002) characterises the set of handheld devices capable of communication using three standard devices: mobile phones, PDAs and pagers. A number of devices overlap several of these categories forming the interlocking set shown in Figure 2-11. At the intersection of these three categories is a range of devices known as communicators that enable voice communication, Internet connectivity, scheduling and computing. Merging the functionality of three devices into one is sought after by users, but presents further challenges for device manufacturers.

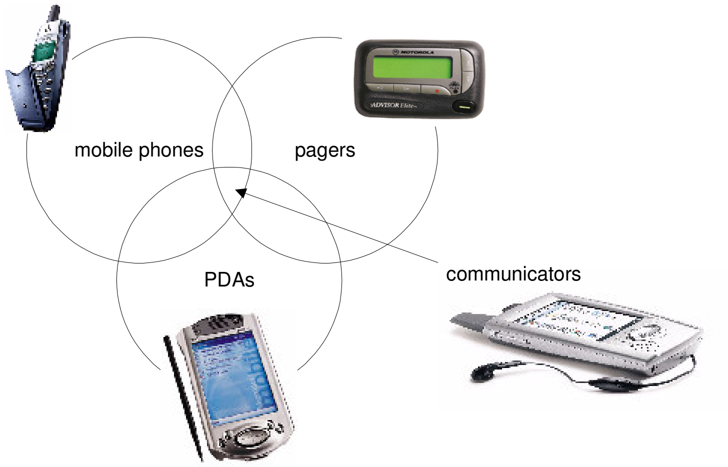


Figure 2-11 Handheld devices (adapted from Weiss 2002 p.4)

The distinction between handheld and desktop computing devices rests mainly with the form factor, or the relationship between the device's size and shape. Designed to be held easily in one hand (and often operated with the other), the size and weight restrictions of handheld devices means that power, processing capabilities and screen size are all limited. As a result they have evolved as useful tools for scheduling, field data entry and communication. Desktop computers with stable power connections, typically constant network connectivity and high data transmission rates are capable of significant processing and designed for longer periods of use. The tradeoffs made by handheld devices are compensated by the potential benefits of mobility, such as access to time-critical information.

Connectivity of handheld devices is dependent on availability (e.g. coverage by mobile phone network) and power. GPRS, a mobile communication network enhancement that offers 'always-on', high capacity, Internet-based content and packet-based data services, provides improved data connectivity for mobile devices. However, the 'always-on' feature promoted by GPRS is still limited by battery resources, and as a result GPRS data services are often configured to deactivate upon extended periods of inactivity. A number of wireless communication methods exist that are capable of providing connectivity for handheld devices. Wireless LANs, 802.11™ and Bluetooth can all offer fast reliable connectivity for handheld devices. However when these protocols are not available, it is possible to use mobile phone networks. These networks offer slower, less reliable connections however are more widely available.

In addition to the bandwidth limitations of cellular networks, connectivity may still be perceived as slow due to the latency of the connection. Latency is defined by Weiss (2002) as ‘the amount of time one has to wait before a data transfer starts’. In circuit-switched networks (such as GSM) a dedicated connection between the receiving and transmitting devices is required before data transfer can occur; in some cases this can take up to ten seconds (Weiss 2002 p.11). In packet-switched networks, such as GPRS and those used by desktop computer Internet protocols, this connection time is not required. Transmission occurs when network capacity is available and the receiving device restructures the data packets when all are received. The networking infrastructure used by desktop computers has been specifically designed for data transmission and upgraded over many years to support this purpose offering a reliable service. Cellular networking infrastructure is primarily designed for transmitting audio traffic which has less stringent requirements (Gupta 2000). Handheld device interaction is specifically related to the particular device; mobile phones have a numeric keypad as the basis of interaction, PDAs may have hardware buttons but often primarily rely on the use of a stylus either clicked or dragged across the screen. These interaction forms differ from the more familiar desktop computer interaction (of full alpha-numeric keyboard and mouse) and can often be cumbersome to use whilst mobile (refer to Buchanan et al. 2001; Kristoffersen & Ljungberg 1999).

Due to a limited memory capacity, Weiss (2002) notes that handheld devices have typically taken on a role of portable information systems, relying on synchronisation with master information systems maintained on desktop computers. With the introduction of LBS applications, handheld devices seem to be adapting this role to one of a tool for the purposes of decision support.

2.5.3 Information Access Methods: Desktop and Handheld Computing

There are a wide range of devices that can be used for Web based access to information which fall within two main categories: desktop computing and handheld computing. Laptop computers can be classified as bridging the gap between desktop and handheld computers, but in this analysis are included in the desktop computing category. Desktop computers are powerful processing machines that are composed of a central processing unit, display device, keyboard, pointing device, and cables to connect the components to each other, to power and to a network. Desktop computers are placed on desks and rarely moved. Handheld computing devices are portable, self-contained information management and communication devices. Weiss (2002) specifies three tests, by which to define handheld devices:

- Cable free operation (except temporarily for recharging or synchronising with a desktop);
- Easily used while in one's hands (as opposed to resting on a table) – held in one hand and operated with the other; and
- Support application installation or Internet connectivity.

The two different hardware setups need to support two very different paradigms of use. Desktop users sit in front of the device for long periods of time, and therefore require comprehensive access to data. Handheld users operate the device in a more irregular way, to solve problems immediately (e.g. double checking schedules or telephone numbers) over shorter durations. The trade-off for rapid, mobile information access comes in the form of limited processing power and power supply. Table 2-4 describes in more detail some of the differences in the two browsing styles.

Table 2-4 Desktop and handheld browsing attributes
(adapted from Weiss 2002 p.16)

	Desktop	Handheld
Browsing style	*Surf* Desktop users with fast processors and high-speed connections, view the Internet as an entertainment medium.	*Hunt* Handheld device users with limited processing power and unreliable connections tend to 'hunt' for information, using the Web for a specific purpose.
Costs	*Fixed* Many desktop computer uses enjoy unlimited Internet access for a fixed monthly fee.	*Time or Data Based* Handheld device users typically pay a monthly subscription fee for Wireless Web access, and are then charged premium time or data quantity prices.
Information access	*Unlimited* Web access is typically unrestricted in the particular pages or content available to users.	*Restricted* Referred to as a 'walled garden' approach to browsing, wireless Web users are often restricted by carriers in the pages that they may access. Additionally, accessing the appropriate area in which to enter a specific URL is often difficult.
Bookmarking	*Simple* Recording and saving useful site addresses for future use is a common and easily implemented feature on the Web.	*Arduous* In traditional browser applications available on PDAs, saving site addresses is an easy task. WAP browsers however often do not provide easy access to this functionality. New guidelines are under development to minimise this problem.
Privacy and security	*Public and Insecure* Typically used by more than one person, desktop computers offer limited privacy and security.	*Private and Secure* Handheld devices are typically used only by their owners and thus provide higher privacy and security levels. Their small size and high value however, make them easier to lose and targets for theft compared to desktop computers.

In terms of Web information access, desktop computers with direct wireline connection to servers and service providers enable users to connect to potentially millions of websites that exist on the Internet. Handheld devices typically rely on a wireless connection to the Internet, which, depending on the form of the connection, can be unreliable and restricted in terms of the information and quantities of information that can be obtained. The small screen format of handheld devices means that many web pages cannot be viewed suitably on mobile devices. Many of the larger screen format handheld devices, such as PDAs, have developed sophisticated algorithms that compress or 'clip' standard web pages to enable viewing them on the mobile devices. As an alternative to the traditional Web for portable, networked, handheld devices, the Wireless Web has emerged. Embedded within the Internet, the Wireless Web describes a subset of the Web that is specifically designed for handheld devices. This includes WAP sites and HTML (Hypertext Markup Language) sites designed for small displays. In addition to the Wireless Web, custom Internet-enabled applications have been designed for handheld computer users that capitalise on handheld device interface features and Internet connectivity.

Having described the three components of LBS: position, information and communication; the following section examines the classification of LBS applications.

2.6 LBS Categories

The commercial LBS market is often described as providing applications to serve the following segments for end users:

- Safety services;
- Information services;
- Tracking services;
- Remote services; and
- Billing services.

(Blonz & McCarthy 1998 p.9)

Mobile GIS (occasionally referred to as field force LBS) and other specialised spatially related mobile applications are also gaining prominence in the industry sector. However LBS for end users who are not specifically trained in spatial information usage or management are the focus of this research.

As summarised in Table 2-5 individual organisations justify the cost of investing in LBS by developing applications that fall within these five categories. Of initial prominence, in response to the US and European legislative mandates, are safety services which have the potential to offer valuable and potentially life-saving benefits to subscribers. To a less critical extent services that fall within the categories of information, tracking, remote and billing are predicted to promote widespread adoption of LBS. Across the example applications shown in Table 2-5, no applications could be classified solely as remote services, however the notion of mobility implied by LBS applications suggests that each of the examples could be classified as such.

In some instances, LBS are categorised according to the dynamism of the information contained within them. Koh and Kim (2000) classify services involving traffic, optimal routing or vehicle tracking as dynamic, and information services (such as for hotels, restaurants and shops) as static.

Table 2-5 Example LBS

Source	Safety	Information	Tracking	Billing
Applications that seem to 'hold promise' to justify the expense of installing a location system (TruePosition 2000)	• emergency management		• inventory/package monitoring • vehicle and fleet management	• location sensitive billing
Classes of location services (Souissi & Phillips 2000)	• E911 • road assistance • health monitoring • rescue service	• locate attractions along route • closest attraction • weather alerts • location based WAP push • abbreviated dialling	• tracking on demand • asset tracking • child locator • stolen vehicles locator • continuous tracking • fleet management • vehicle tracking • automatic tracking and alert • turn by turn directions • personal/vehicle navigator • low risk prisoner movement • fixed asset movement	• location specific advertising
General categories of location-based services (McCabe 1999)	• E911 • emergency roadside services • early warning evacuation	• traffic information • lifestyle information • 411 information	• fleet management • package tracking • children tracking	• location sensitive billing • wireless office • residential cordless
Categories for wireless location services (Webraska 2001)	• end-user assistance services	• location based information services • routing and navigation services	• tracking services	• location based commerce

While the method of classification is not essential it does help to understand the types of services that can be provided within the realm of LBS. As noted by Niedzwiadek (2002 p.8) ‘the full value of location services will stem from location content and the underlying GIS functions that apply this content to tasks at hand’. As technology improves and more LBS suitable content becomes available, an increased range of services related to a user’s location will emerge.

2.7 Conclusions

Mobile computing restrictions mean that it will be unlikely for handheld mobile devices to match the computational resources and viewing capabilities of desktop PCs and high end workstations. However, this is not the intention of such technology. The key lies in finding the mechanisms to enable mobile users to access small, appropriate sections of larger data sets in a spatial decision making capacity.

LBS in the wireless environment aim to capitalise on the unique knowledge of a user’s (or some target’s) position in order to provide contextually relevant information to them to assist in their decision making process.

The possibility of pinpointing mobile phone users for safety purposes is one of the driving forces leading the refinement of positioning capabilities, and as a result providing the basis of an infrastructure for LBS. The wide range of services that can be offered to mobile users based on their position demonstrates the potential reach for LBS. Integrating real-time information with the position relevant information of LBS will provide enhanced value to users.

The next chapter provides the background for SDI, the importance of spatial information and highlights the synergy with LBS.

Chapter 3 Spatial Data Infrastructure

As identified in Chapter 1, the SDI concept evolved as a result of increased recognition and importance being placed on spatial information. The need arose to formalise data sharing and collaboration efforts in an attempt to minimise duplication of effort and resources.

To understand the existing SDI model, and how it has evolved to its current form, the theory of SDI and its evolution is presented. This chapter examines the reasons why the SDI concept was introduced, some of the varying definitions for SDI and the identification of common elements between these definitions that have been combined to form a model for SDI.

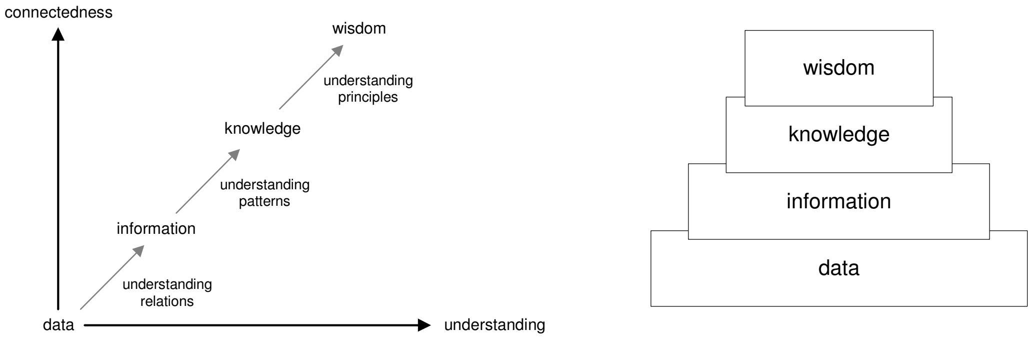
3.1 Introduction

The concepts underlying SDI trace back to improving and optimising access to and utilisation of geospatial data sets. 'Geospatial data' refers to the subset of spatial data that is related to the Earth, but the terms spatial and geospatial are often used interchangeably. The sentiment behind the data-sharing environment promoted by the SDI initiative is not new. Professor Albrecht Penck is attributed with initiating the compilation of a map of the world at a scale of 1:1,000,000 in 1891. Publishing this information as a series of map sheets at a uniform scale, projection and cartographic style was expected to eliminate the difficulty in knowing what maps existed and obtaining access to them, as was often experienced as a result of the fragmented publication manner of the time (Groot & McLaughlin 2000).

Now, data sharing principles can be employed using a variety of computing and communications infrastructures. The move into the information and digital ages over the last thirty to forty years has propelled these ideals and provided a means by which a broad user group (from general citizens to expert users) now has access to spatial information.

3.2 The significance of spatial information

Information is a valuable and often expensive resource and typically regarded as falling between data and knowledge, or as a superset of data and subset of knowledge, in the data-information-knowledge-wisdom continuum (refer to Figure 3-1). While the definitions for each of the components are a continual source of debate (refer to Clampitt 2001; Ackoff 1999; Merali 2001) and the relationships between them are somewhat circular and connected, data and information play a critical role in achieving and appropriately acting on knowledge as part of the decision making process. Data are typically raw observations, while information is data that are ordered and contextualised in order to provide meaning. Knowledge is then the cumulative understanding of information based upon a model. Indeed the economic importance of information has grown steadily since the period of industrial expansion in the middle of the nineteenth century (Hepworth 1989).



(Bellinger, Castro & Mills 2003) (Steyn 2001)

Figure 3-1 Two representations of the data-information-knowledge continuum

Spatial information has paralleled the economic developments of information. Recent figures indicate that sixty to eighty percent of all information held by governments can be classified as spatial (Lemmens 2001; Coopers and Lybrand 1996; Masser 1998). The inherent ability to overlay and integrate various spatial datasets for analysis and knowledge gathering purposes enhances the value of spatial information (Masser 1998). A commonly cited example of the value in combining spatial datasets is the work of Doctor John Snow who, in 1854 verified that a deadly organism (later determined to be cholera) was water-borne. Snow identified a correlation between the location of fatalities and water pumps in London, and by representing this information in map form, was able to demonstrate support for his hypothesis (Frerichs 2000).

In response to the importance of spatial information, many initiatives are emerging to improve access to and reuse of these valuable resources. For example in the SDI Cookbook, which is a practical guidebook for SDI implementers, the importance of ensuring that the 'investment in spatial information collection and management results in an ever-growing, readily available and useable pool of spatial information' (Nebert 2000 p.5) is stressed.

3.3 SDI Concept Evolution

Spatial and particularly geospatial data has, over the last few decades, been regarded as an increasingly important commodity. Used across the private, public and academic sectors, geospatial data exhibits an almost unique behaviour in that it has the potential to be used in many applications and for many different purposes. With appropriate and consistent data collection and spatial referencing procedures, the correlation and integration of various geospatial data sets has become a relatively easy task achievable on desktop personal computers. However this was not always the case.

As noted by Worboys (1998 p.2), 'we all exist within a spatial and temporal world and have a need for information that has spatial and temporal dimensions'. The need to draw, represent and model the Earth and in particular the land, ownership and other practices that occur in relation to it has been an important activity for centuries and have been the basis for SDI (Steudler 2003 p.236).

These activities were persistent throughout the move to the digital age. As early as the 1960s computers were being used to model the Earth (Niedzwiadek 2002). While somewhat primitive by current standards, these were the foundations for what we know today as GIS. This technology facilitated the integrated mapping concept, enabling the registration, overlay, interpretation and analysis of different themes of geospatially related data sets to assist in solving practical problems (McLaughlin & Groot 2000). Typically these systems were centralised 'databanks' or repositories, under the jurisdiction of national mapping agencies or governments.

In the 1970s, GIS was beginning to take shape and a series of major topographic and cadastral 'base-mapping' programmes designed to support land administration at various jurisdictional levels were launched around the world (McLaughlin & Groot 2000). Many nations, and in particular their surveying and mapping agencies, had identified the need to develop standardised strategies and processes for accessing and using geospatial data (Groot & McLaughlin 2000). Initially, a technical approach was adopted with the development of standards for storing and accessing spatial information. However it was recognised that these encapsulated only half the situation, and standardisation requirements were soon broadened to encompass the institutional and organisational issues accompanying the technical processes. All of these initiatives were intended to reduce duplication of effort by map makers (including both data capturers and analysts).

As the information revolution continued through the 1980s, information became commonly regarded as a corporate resource. This paved the way for what McLaughlin and Groot (2000) refer to as the 'information resources management movement' which encouraged organisations to collect, manage and share hard copy and digital resources that were of corporate-wide interest. Unlike the systems of the previous decades, the collective approach involved linking and networking individual data custodian organisations to form a ''virtual' geographic information system which could be queried in a manner similar to a single database' (McLaughlin & Groot 2000 p.270).

Establishing large spatial databases in this manner required significant financial investments. In the process of justifying the expense involved and the business cases for the future improved access to data provided by these databases, Canada referred to these initiatives using the term *data infrastructure* (Groot & McLaughlin 2000).

While initially a relatively intuitive term, incorporating both the technical components and organisational processes associated with data sharing, the term *infrastructure* soon led to confusion due to a range of definitions. Traditionally infrastructure was used to refer to physical objects or entities 'to be shared by participants in some kind of common endeavour' (Groot & McLaughlin 2000 p.4). For example, objects such as roads, pipelines, ports, factories, airfields and telecommunications networks were often referred to as infrastructure. The use of the term broadened over time and was intended to include the institutional, regulatory and financial elements necessary in the design, creation, maintenance and use of the hardware or physical components, previously referred to as infrastructure. The term has also come to include the processes that promote or facilitate broad social participation (Groot & McLaughlin 2000).

Despite the varying definitions, the use of the term *infrastructure* has prevailed due to the implicit understanding that it refers to a reliable supporting environment, analogous to a road. Prefaced with phrases such as 'spatial data' or 'geospatial information' to specifically refer to the collaborative data resources developed and maintained for decision makers, analysts and government authorities in the spatial domain, the notion of the underlying supporting environment endures. Nebert (2000 p.7) points out that 'like roads…an SDI facilitates the conveyance of virtually unlimited packages of geographic information'.

The principles of spatial data sharing and minimising duplication of effort continued through the 1990s. Nation-wide information networks were established in the USA, Canada, Australia, the United Kingdom, and throughout the European Community, forming the first series of National (and in the case of Europe, Regional) SDI initiatives. The following section provides a formal definition for SDI, explaining the constituent components and their hierarchical nature.

3.4 Definitions and components

Many definitions exist for SDI depending on the scale and frame of reference for each initiative (refer to Chan et al. 2001). In this thesis, Groot and McLaughlin's definition of Geospatial Data Infrastructure has been adopted but is referred to as Spatial Data Infrastructure since the infrastructure is equally valid for non-Earth related data:

> 'Geospatial [or Spatial] Data Infrastructure encompasses the networked geospatial [or spatial] databases and data handling facilities, the complex of institutional, organisational, technological, human, and economic resources which interact with one another and underpin the design, implementation, and maintenance of mechanisms facilitating the sharing, access to, and responsible use of geospatial [or spatial] data at an affordable cost for a specific application domain or enterprise.' (Groot & McLaughlin 2000 p.5)

SDI are intended to create an environment which enables a variety of users to access and retrieve complete and consistent data sets in an easy and secure manner (Coleman & McLaughlin 1998; Rajabifard et al. 2000). Typically this is accomplished through the development of dynamic partnerships between inter- and intra-jurisdictional organisations, and as noted by Groot and McLaughlin (2000) are applicable for a specific application domain or enterprise. Feeney and Williamson (2000 p.95) also indicate that SDI 'have the potential to increase business opportunities for the geographic information industry, and promote widespread use of available data sets'. Encompassing issues of people and user environments; network access; policy, privacy and liability; standards and interoperability; and data quality, SDI enable efficient collection, management, access, delivery and utilisation of spatial data in a wide range of contexts.

Irrespective of the fact that stakeholders from various disciplines view SDIs differently, researchers have identified a number of core components that are common to all SDI implementations (Coleman & McLaughlin 1998; Rajabifard et al. 2000; Rajabifard & Williamson 2001). As shown in Figure 3-2 these components are: people, access network, policy, technical standards and data sets. Each is strongly related to the other four resulting in a cohesive infrastructure.

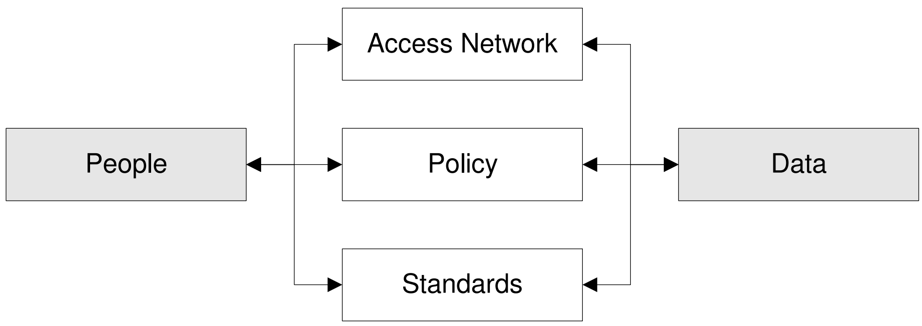


Figure 3-2 SDI components (Rajabifard & Williamson 2001 p.5)

Whilst individual SDI implementations will define each of these components in detail, specific to their intended use, this model provides a sound foundation from which to explore the principles underlying the SDI initiative.

Each of the five components is described briefly below and examined in more detail in relation to LBS in Section 3.7.

The *data* component comprises the core data elements for the SDI. For example a state SDI could define geodetic control, cadastral information, administrative boundaries, elevation and hydrology data themes as fundamental.

The avenue by which data within an SDI is made available to the community, can be described as the *access network*. Access arrangements must be made in accordance with the policy decisions and technical specifications defined within the implementing organisation's institutional framework.

The institutional framework of the organisation implementing the SDI defines the *policy* and administrative arrangements for collecting, maintaining, accessing and applying the standards and data sets.

The *standards* component defines the technical characteristics of the fundamental data sets. These can include metadata, data dictionaries, data quality, data transfer, reference systems and data models.

The *people* component of an SDI encompasses the diversity of the users and producers of spatial data (including value-adding agents).

3.5 Hierarchy

Many nations are developing SDI to better manage and utilise their spatial data assets. As developments progress, some countries are finding it necessary to cooperate with others to develop multinational SDIs to assist in regional decision making that has an impact across national boundaries. From this, a hierarchical structure of SDI has resulted with perspectives moving through local, state, national and regional levels to a global level. This hierarchy mirrors the typical government breakdown of responsibility for land management issues from the national level through state levels to the local level, and is used to refer to the scale of the SDI or the geographical extent of the data within it.

Rajabifard et al. (1999) identify two views of this hierarchical structure of SDI (refer to Figure 3-3). The umbrella view examines the hierarchy from the top down. The SDI at the higher level encompass all of the components of the underlying SDIs. For example at the global level the necessary institutional framework, technical standards and access networks should be in place to facilitate the sharing of the fundamental data sets which are kept at the lower levels. Conversely, the building block view examines the hierarchy in the opposite direction, with each of the lower level SDIs acting as the supporting blocks to provide the spatial data needed by those at the higher levels. This double view of the SDI hierarchy creates an environment in which decision makers working at any level can draw on data from other levels, and conforms to the Janus effect defined within the theory of hierarchical reasoning (Rajabifard, Escobar & Williamson 2000).

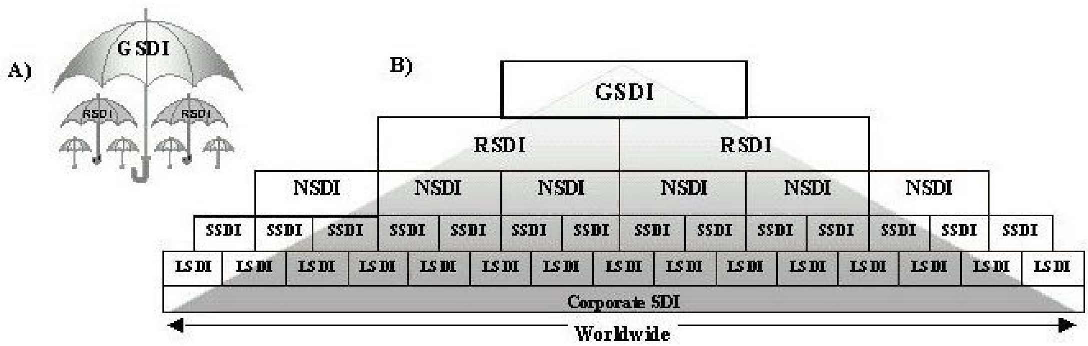


Figure 3-3 SDI hierarchy views A) Umbrella view B) Building block view (Rajabifard, Chan & Williamson 1999 p.3)

For this research, SDIs at the corporate and local level are of most relevance. However, the hierarchical nature implied by the SDI concept cannot be overlooked as it is these lower level SDIs that provide the foundations for the higher levels.

Corporate or local level SDIs (LSDI) will typically be relevant for a small geographical area such as a local government jurisdiction. The data stored in SDI at this level usually form the foundation data for subsequent levels. While this SDI level can operate independently of the others, it is likely that the fine, detailed data available may be of use (even in an abstracted or aggregated form) to higher levels in the hierarchy. Consequently, standards and policies should be developed to be flexible enough to facilitate aggregation and integration from higher levels. Groot and McLaughlin (2000) caution that applying compatible standards from the top down (i.e. when the need arises for local data to be accessed by a state SDI) can be a time-consuming exercise. Therefore developing these policies from the outset is advised.

State level SDIs (SSDI) rely on the foundation data of the underlying local SDIs, however they also form the basis for the SDI at the next level – national SDI.

National SDIs (NSDI) support the sharing of data within a national context. This is achieved primarily through appropriate standards for reference systems, elevation models, administrative boundaries, thematic data sets and metadata (Groot & McLaughlin 2000).

Regional SDIs (RSDI) are required for areas of interest that cross administrative boundaries (including national boundaries). Data needs to be standardised from the relevant national SDIs and policies developed for the regional SDI that are consistent with the participating national SDIs.

At the smallest scale, *global SDI* (GSDI) support global-domain applications. As for the other levels, appropriate referencing systems, models and classifications are required. As noted by Groot and McLaughlin (2000), the major challenge for this scale SDI lies in adhering to the policies of each of the contributing SDIs.

3.6 Architecture

To achieve the data sharing principles advocated by SDI initiatives, computers and databases need to work together. This section provides the background on the communications network architectures that allow SDIs to become a reality.

3.6.1 Computer Networks

The technical details of the computing and networking elements of an SDI are really the scope of the Information Technology (IT) and Communication domain, however since they play such a critical role in an SDI implementation, an understanding of how they work is necessary here.

As discussed briefly in Section 3.3, the computing systems that contributed to SDI implementations evolved from centralised to decentralised systems. Initially, all processing, software and hardware elements of a computing system were physically located at one place. Transactions involved taking input data to the central system where it was processed, and then physically delivering the output to users. These systems quickly proved inefficient, and decentralised systems emerged where several computers were connected to a central computer and could individually carry out small quantities of processing. Today distributed data processing is commonplace with thousands of computer networks existing around the world.

A computer network is a system that uses communications equipment to link a collection of autonomous computers, with typically no hierarchical relationship between them. Messages are transmitted from one computer to another as a series of digital bit streams via some medium. Kainz (2000) distinguishes between media types classifying them as either guided (e.g. cables, fibre optics) or unguided (e.g. radio, microwaves). Each media type has its own bandwidth limits, installation and maintenance methods, and costs, all of which must be examined and evaluated for the proposed network use.

3.6.2 Client-server architecture

Amongst a range of network types, is the client-server architecture. This common form of distributed system splits processing tasks between client computers and a server. A client is a process or computer that requests a service of another computer using a set of standard rules or protocols. The server receives and processes the request and returns the result to the client.

With this architecture, users are separated from the processing task, often not even aware of whether the processing is occurring on their client machine or remotely on the server, hence this system can be regarded as behaving ‘as a virtual single processor’ (Kainz 2000 p.114).

The Internet, itself a loosely organised collection of thousands of networks, operates under the client-server architecture. Requests from individual computers are passed on to the appropriate servers which process the requests and return the output to the requesting computer. Within the Internet, the WWW relies on HTTP to transmit queries and responses. Under HTTP version 1.0, query-response pairs are treated independently with no record of previous queries made by particular users being maintained. This inability to establish user sessions has been one difficulty with Web based GIS applications that has led to the need for additional software components to enable this functionality (Green & Bossomaier 2002).

3.6.3 SDI Architecture

Collecting, storing and arranging access for remotely stored data sets is a large part of an SDI implementer's role. A more pressing challenge however, as described by Bishr and Radwan (2000), lies in making the information that has been collected and stored within a networked system known about and easily accessible and comprehensible to a large range of users. The availability of computers and Internet access means that large quantities of spatial information can now be accessed by those outside the expert community. Bishr (2000 p.135) notes that 'this shift is forcing the industry to provide network-enabled software and user-oriented geospatial data services rather than just maps'.

In order to provide awareness and access to spatial databases, the SDI concept requires more than just linking spatial databases together. To regulate access and flow of information Groot and McLaughlin (2000) propose a Geospatial Data Service Centre (GDSC) for each SDI that acts as an intermediary between data users and suppliers for applications within a particular enterprise or domain. Shown in Figure 3-4, the GDSC ensures the integrity of access to data by monitoring the technical as well as administrative processes defined by the SDI that exist between suppliers and users. Data standardisation activities, essential for data sharing, can also be monitored and controlled by the GDSC. As identified by Groot and McLaughlin (2000) clearinghouse activities in several jurisdictions are evolving into GDSCs. It is interesting to note that this concept follows the model of the 'land information centre' of the past fifteen to twenty years (refer to Williamson 1986), with users removed from the spatial data repositories, but able to access spatial data via the land information centre.

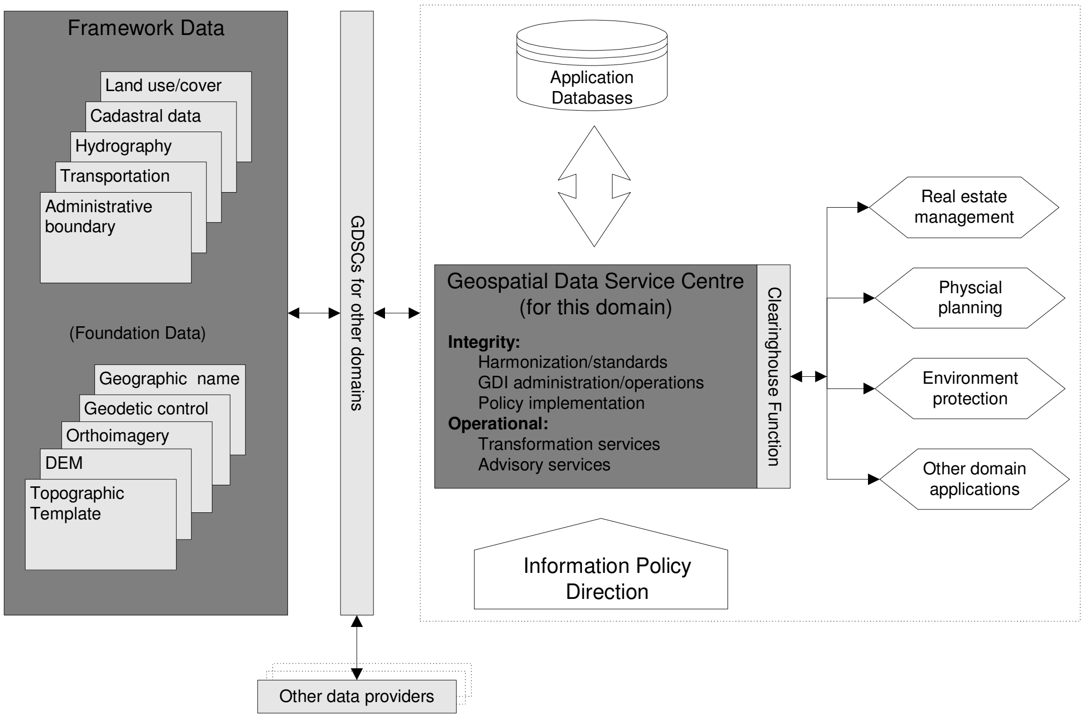


Figure 3-4 Role of a Geospatial Data Service Centre
(Groot & McLaughlin 2000 p.5)

The range of SDI implementations around the world, that are using this architecture (or slight modifications of it) are helping to increase awareness of spatial information and its potential use to a dispersed non-expert user group. The potential access methods of this user group are advancing from fixed media Internet access to that of wireless Internet access using networked portable handheld devices. These access methods will be examined in greater detail in the next chapter.

3.7 SDI Model Evaluation

The SDI model developed by Rajabifard and Williamson can be regarded as a conceptual model as it describes a system in generic terms without reference to particular implementations (Whitten, Bentley & Dittman 2000).

While there are many ways in which to verify or validate a conceptual model, Khazanchi (1996) defines eight criteria as a minimum set of desirable qualities for a concept or conceptual model:

1. Plausible;
2. Feasible;
3. Effective;
4. Pragmatic;
5. Empirical;
6. Predictive;
7. Inter-subjectively certifiable; and
8. Inter-methodologically certifiable.

Since the SDI model (refer to Figure 3-2) was developed prior to the maturation of mobile phone and wireless technology, it was unlikely that it would be able to fully account for wireless data dissemination and the multitude of applications that this technology is now beginning to allow.

In the wireless domain, the basic SDI concepts of people accessing data through a system of networks, standards and policies remain valid. However, given the restricted and limited environment of wireless information dissemination to mobile users, it is likely that a range of additional issues need to be accounted for within the SDI model.

As summarised in Table 3-1, analysing the SDI model according to Khazanchi's criteria (Khazanchi 1996) confirms that the current model is valid but only partially so for the specific situation of supporting wireless information access.

Table 3-1 SDI model assessment

Criteria	Definition	Criteria Satisfied	Explanation
Plausible	Is the concept or model reasonable as demonstrated by corroboration or deduction from past research or theories, or developed on the basis of observation or induction?	✓	Model has been developed from a wide range of operational SDI definitions.
Feasible	Does the concept or model have the quality of being workable or operationalisable – i.e. amenable to verbal, graphical, mathematical, illustrative, prototypical characterisation?	✓	The SDI model is a graphical representation of the SDI concept and is appropriate for existing SDI implementations.
Effective	How effectively does the concept or model describe the phenomena under study?	(✓)	The model describes the SDI concept at a very coarse level, and whilst sufficient at a generic conceptual level it provides little practical guidance for wireless SDI initiatives.
Pragmatic	Does the concept or model subsume conceptual structures that previously explained related phenomenon? Does the concept or model have some degree of abstract, logical self-consistency or coherence with other concepts and conceptual models in the discipline?	✓	Developed from operational definitions, the model encompasses the concepts of previous models.
Empirical	Is the concept or model empirically testable?	(✓)	The coarse level at which the model is defined does not readily invite empirical testing, however it does not prevent it.
Predictive	Does the concept or model explain a phenomenon that is expected to occur?	✓	The model demonstrates the relationships between the key components in an SDI at a broad level. However, these relationships differ when examining specific roles within the wireless environment.
Inter-subjective	Is it possible for investigators with differing philosophical stances to verify the imputed truth content of the concepts or conceptual structures through observation, logical evaluation, or experimentation?	(✓)	At a high level, the SDI model can be verified by investigators from differing backgrounds and using differing methodologies.
Inter-methodological	Is it possible for investigators using different research methodologies to test the veracity of the concept or conceptual model and predict the occurrence of the same phenomenon?	(✓)	

Exploring the weaknesses of the SDI model from a wireless perspective, the following sections take a localised view of each of the SDI model components and highlight how they need to adapt in order to support wireless information access and dissemination.

3.7.1 People

Through increased use and awareness of spatial data, a dramatic growth has occurred in the user base of spatial information. With the proliferation of online web mapping, and navigation/direction information, an increasing number of people are using GIS and spatial information often without even realising they are doing so (refer to (Pühretmair, Rumetshofer & Schaumlechner 2002) for an analysis of users of web based tourism sites). For example many users of popular map, directions and routing sites such as MapQuest™ (http://www.mapquest.com) in the US or Whereis® (http://www.whereis.com.au) in Australia would not be aware that they were interacting with a GIS. The provision of spatial information to handheld devices will continue to increase the spatial information user base. The nature of this growth means that SDI based applications now need to cater for non-expert users.

As highlighted in Figure 2-3, the people involved in LBS deployment include: content providers, location providers, platform developers and application developers. From an SDI perspective these categories can be re-classified into three groups: (i) data providers (content providers and location providers); (ii) integrators (platform developers and application developers); and (iii) end users (refer to Figure 3-5). Data providers collect and create the spatial (and a-spatial) databases for the SDI, and perform the positioning determination for the LBS application. Integrators are responsible for designing and implementing LBS applications. End users, who were previously erroneously overlooked, have now been included since they are the people who use the LBS applications on their handheld devices. These groupings also reflect the range of spatial knowledge from data providers, who are highly trained and experienced in the use of spatial information, through to end users, who may not necessarily be trained in the use of spatial information but should still be able to use an LBS to solve their spatial problems, and assist them with their decision making.

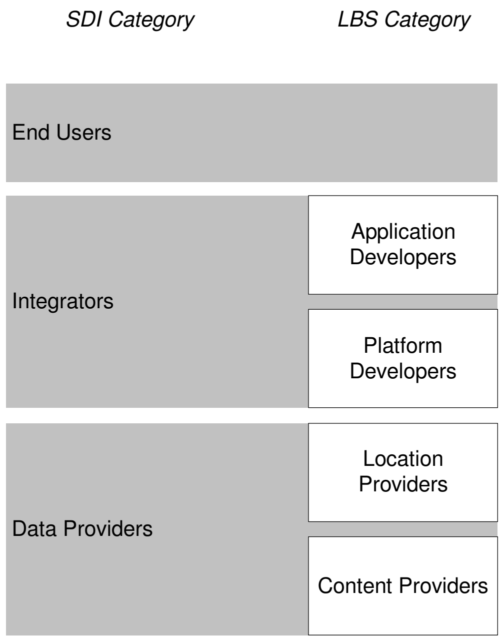


Figure 3-5 SDI people categories formed from LBS categories

Wireless LBS will help to promote the use of spatial information by a broad proportion of the community. Whilst capacity building initiatives encompassing a range of education and training programmes would be useful in enabling the wider community to become more spatially aware and literate, it should not be a prerequisite for LBS use. Particularly in the early stages of these services, it is the responsibility of data providers and integrators to develop intuitive services that can be used by the general community, irrespective of their spatial ability and knowledge. As society becomes more technically savvy, spatially aware and more demanding of services available through handheld devices, more detailed and enhanced services are likely to be required. In a white paper by Gravitate (2000) these expected developments are described as successive generations of LBS.

3.7.2 Access Network

The avenue by which data within an SDI is made available to the community, can be described as the access network. Access arrangements must be made in accordance with the policy decisions and technical specifications defined within the implementing organisation's institutional framework.

In the early SDI implementations, sharing data relied on the physical relocation of data from providers to users. Networked computing and the Internet have now become pervasive, and accordingly online clearinghouses and distribution centres are being developed to enable people to gain access to data more easily.

Wireless communication is also providing an alternative avenue for information access. Unlike the other access mechanisms, this method has specific limitations that are requiring existing access standards and policies to be re-examined. The most prominent issue in this respect is that of bandwidth.

Bandwidth is the width of a band of electromagnetic frequencies of a signal, essentially the amount of frequency spectrum that a single electronic signal occupies (Held 2000), and is generally expressed in terms of the speed at which data can flow on a particular transmission path – bits per second (bps). Fixed line modems and Local Area Network (LAN) Ethernet connections with bandwidths of 56kbps and 10Mbps respectively, offer much more scope for data transmission when compared to the most prevalent wireless telecommunications system, the GSM network which offers a bandwidth of only 9.6kbps.

Despite developments to improve the bandwidth available over wireless networks (such as High Speed Circuit-Switch Data, GPRS and 3G services – which require new telecommunications infrastructure investment), it is unlikely that they will ever be able to match the capacity of fixed line connections and therefore data transmissions should be kept to a minimum. This will not only ensure that the wireless network does not operate close to capacity at all times, but will also enhance the user's experience by providing prompt responses. Using location as an information filter can also help to restrict data flow. Rather than sending a mobile user who is searching for a restaurant the complete yellow pages directory entries for restaurants, a small section of the entries need only be returned – those that list restaurants in the user's current (or future) area. This is also a more usable and useful solution for users.

Whilst increasing bandwidth may be feasible from a network perspective, it introduces another problem. In order to process more bandwidth, more power is required. Handset form factors limit the size of batteries and hence the available power of mobile devices. Therefore wireless data solutions must be able to overcome these network limitations to still deliver a satisfactory experience to the user. A balance must be found between bandwidth and the power required to process it.

In terms of wireless Web data transmission, the current standard is WAP. WAP is designed to complement existing wireless standards, but does not specify how data should be transmitted over the air interface. Rather, WAP 'sits on top' of existing bearer channel standards (including SMS, Circuit Switched Data, Unstructured Supplementary Services Data or GPRS) (Buckingham 2000). This means that any bearer standard can be used with the WAP protocols to implement product solutions (MobileInfo.com 2001). WAP is also optimised for the limited functionality and display capabilities of current mobile terminals.

While most of these observations relate to the end user's experience, access issues are also of concern to integrators and data providers. Integrators need to ensure that the data they are enabling access to is appropriate for the intended purpose, and presented in a useful form to end users. Additionally, services that the integrator develops need to provide seamless data access (alleviating the user from having to understand the underlying infrastructure) and be both responsive and sympathetic to the network mechanism through which the access is being provided (particularly in the case of wireless networks with limited bandwidth). In the process of developing applications, integrators must have appropriate access mechanisms to the underlying data – a catalogue or repository of data sets available and suitable for LBS could be established as part of the infrastructure. Data providers, whose data is useful for, and conforms to appropriate standards for LBS, should advertise their data through such a catalogue service to facilitate the sharing and reuse of data sets.

3.7.3 Policies

The policy and administrative component of the SDI definition is critical for the construction, maintenance, access and application of standards and data sets for an SDI implementation. In general, policies and guidelines are required for SDI that incorporate:

- spatial data access and pricing;
- spatial data transfer;
- custodianship;
- metadata; and
- standards.

Whilst these policy and administrative arrangement categories may be appropriate for SDIs that support fixed line data access, they also need to be appropriately structured to accommodate wireless data transfer. Additionally wireless communication poses additional privacy concerns and thus privacy policy or regulations should also be a part of an LBS SDI policy definition.

Throughout its history, the nature of the spatial information industry, and the use of spatial technologies have raised concerns regarding personal information privacy, intellectual property rights of geographic information, liability in the use of geographic data sets, public access to government geographic data sets and the sale of geographic information by government agencies (refer to Clarke 2001; Cho 1995; Onsrud, Johnson & Lopez 1994). The evolving domain of LBS that is often reliant on position determination of a mobile device (and hence its user), raises further concerns amongst end users (or subscribers). Irrespective of these emerging applications, tracking is inherent in existing telecommunications networks, albeit at a coarse level (refer to Section 2.3.2). In cellular networks, location monitoring is required in order to direct incoming calls to the appropriate device (through the relevant cell’s base station). The accuracy of the position can range from less than 1km to approximately 20km, and the movement of mobile users can be inferred from temporal analysis of these tracking records. Whereas the traditional telephony model identifies a location through a telephone number, mobile telephone numbers now identify a user (the location of whom can be determined from network records). While these records are not typically available to the general public, telecommunication companies have recently become aware of the benefits associated with analysing this data (Clarke 2001).

LBS extend the position information that can be obtained about a mobile device at a particular time, by using this position variable to provide specialised content to users. While currently LBS in themselves do not pose any further infringements of privacy, they are increasing awareness of the ability to pinpoint a user through their mobile device. As improved location techniques are devised and positioning mechanisms are implemented in the devices themselves, users are likely to become more concerned with this range of services and the use of data that is kept about them.

As a result, policies must be put in place to ensure the appropriate use of personal and location data captured via telecommunications. In Australia, these policies must be inline with the recently introduced *Privacy Amendment (Private Sector) Act 2000* to the *Privacy Act 1998* (Cth) which aims to 'regulate the way many private sector organisations collect, use, keep secure and disclose personal information' (Office of the Federal Privacy Commissioner 2001). The policy component in an expanded SDI should include the existing elements of pricing and data standards, but provide specific details for the wireless access and dissemination of data. An expanded SDI should also include a policy for personalisation of the service. Even though the details of these policy issues will vary for each LBS implementation, there should be some generic principles that could be recommended at the infrastructure level.

3.7.4 Standards

To ensure interoperability amongst the data sets and access mechanisms defined by an SDI, standards are essential. Standards can be applied at many different levels within an SDI. In terms of data, Australia's former national mapping organisation, the Australian Land Information Group, AUSLIG (2001) identify that standards are required 'in reference systems, data models, data dictionaries, data quality, data transfer and metadata'.

While it is commonly accepted that standards are an essential requirement in the deployment, continuing support and development of a successful SDI, it is often not clear which standards should be adopted to achieve this aim. The spatial information industry has many standards for each of its discipline and technical areas, resulting from the independent and proprietary nature of the industry's foundation. In addition, the strong reliance by the industry on computing technology means that another extensive range of IT related standards are also of relevance.

The classes of standards within the spatial information industry that are relevant to SDI include:

- Data format, exchange and access – for both spatial and a-spatial data sets;
- User design – database schema, data coding and classification, metadata;
- Map compilation and accuracy; and
- Map presentation.

The numerous IT standards are often grouped or themed under categories of portability, inter-operability, information access or maintainability. Standards of relevance to SDI implementers fall under each of these categories, however the most relevant relate to issues such as database design and data exchange procedures (Croswell 2000).

Even though the fields from which SDI and LBS have evolved are well established, these areas themselves are still relatively young and as a result many standards remain under development. Groups such as the International Organization for Standardization Technical Committee on International Geographic Information Standards (ISO/TC211) and the OGC are researching standards related issues for LBS from a global perspective (refer to http://www.isotc211.org and http://www.opengis.org respectively). Similarly on the SDI front, many countries are exploring standards issues in association with the development and implementation of their National SDIs (Viergever 2001; Hissong 1999; Nairn 2000; Arias 2001; Hayes 2001). There are also a number of regional and jurisdictional initiatives, particularly in Europe, investigating the impact and importance of standards on SDI implementations.

From a wireless communications perspective, telecommunications network standards will pose some restrictions on the quantity and format of data that can be delivered wirelessly. Whilst the spatial information industry will have little, if any, input into how these networks should be structured, an understanding of the network capabilities and limitations is essential in order to develop appropriate spatial applications that rely on this medium. As mentioned above, bandwidth limitations will require minimised query and response data flow from users to the applications and subsequently to data repositories. Standard interfaces, such as those proposed by the OGC (refer to Open GIS Consortium 2001), will facilitate this.

As noted by Croswell (2000 p.58), ‘standards are not an end in themselves but the foundation to help make information systems and databases easier to use and maintain’.

Standards on data quality need to be specified for data that can be considered suitable for LBS. While it is critical that all spatial information used in decision making be of appropriate quality for its intended use, the expanded user base encouraged by LBS raises the need for unique quality standard requirements. Users of LBS will typically be accessing the service on a mobile device with limited screen size and resolution. It is likely that they will be simultaneously carrying out external tasks whilst using the service, and will commonly be travelling by car or on foot. Not necessarily being familiar with spatial information, users could have difficulties executing navigation and orientation instructions as portrayed by LBS. Standard presentation formats could assist in the cognition of this information by users and hence the usability of systems. Standards for positional and attribute accuracy of data would also be of use considering the criticality of this information to pedestrians.

3.7.5 Data

Fundamental to any SDI is data. In many SDI definitions a set of ‘fundamental data sets’ are identified as the core data elements. Different SDI initiatives define a range of different fundamental data themes as shown in Table 3-2.

Table 3-2 Fundamental data sets for SDI initiatives

SDI	SDI Scale	Fundamental/Framework Data Themes
Victorian SDI Australia	State	Geodetic Control; • Cadastral • Address • Administrative • Transportation • Elevation • Hydrology • Imagery (Jacoby et al. 2002)
I-Team Geospatial Information Initiative US	State	• Digital orthoimagery • Geodetic control • Elevation • Hydrography • Cadastral data • Politcal boundaries • Transportation (Hayes 2000)
Asia Pacific SDI	Regional	• Geodetic control network • Elevation • Drainage systems • Transportation • Populated places • Geographical names • Vegetation • Natural hazards • Administrative boundaries • Land use (Masser, Borrero & Holland 2003)
Integrated Land Information Services Singapore	National	• Whole Land Register comprising ownership, encumbrances, title, last transaction information, and Land Encroachment Details • Lot Particulars Search • Estate and Proprietor Information • Survey Map, with lot area and Certified Plan numbers • Surrounding Lots Sales Transaction Information • Surrounding Amenities Information • Sales Transaction History Information • State Land Encroachment Information • Certified Plan • Certified Plan Strata Title • Registrar of Title Plan • Strata Title Registrar of Title Plan • Road Line Plan • Control Points Information • Primary School Listing Service • Survey map of a land lot • Survey Plan • Road Line Plan • Locality Sketch or Photo Image of control point (Singapore Land Authority 2003)

Organisations implementing an SDI will specify the framework within which the data sets must preside as well as technical standards defining scale, resolution, format and structure. It should be emphasised that while data is a fundamental component of the SDI, it remains just that, one part; Hoffmann (1999, cited by Rajabifard, Chan & Williamson 1999) proposes that ‘a ‘Spatial (data/information/knowledge/expertise) infrastructure’ should be more than a geographic information infrastructure. It is the spatial integration component for an information society system, which is the important interoperability element of a future information society’.

Interoperability is a key consideration of both the standards and data component of an SDI. Data within an SDI should be compatible in terms of format, reference system, projection, resolution and quality.

A major challenge for the wireless dissemination of spatial data is that of quantity and quality. As discussed previously, wireless communication networks offer restricted bandwidth compared with fixed line networks. Spatial databases can be quite large (in terms of geographic extent, level of detail stored and hence quantity of storage space required).

The nature of mobility means that mobile users will not require access to large portions of data, rather they will be interested in small, detailed data portions that are highly relevant to their current or future position and the surrounding area. Additionally, the format and presentation of this information must be carefully structured. Whether current data models are appropriate to meet these challenges is yet to be determined.

Considering that many LBS applications rely on the same sort of data (e.g. transport networks and address information) which service providers may not wish to maintain themselves, the establishment of an SDI containing these data sets could be feasible. LBS providers could then develop their applications to use data via a standard infrastructure, but could also supplement the fundamental sets with their own data, specifically suited to their application. This would ensure data quality of the fundamental data sets would be maintained, as it would remain a responsibility of the data custodians.

Data quality is an important issue for mobile users who demand information in real time. Users, who typically will not be trained in the spatial sciences, will not be interested in trying to assess the quality of information that they are receiving. Rather, they will expect the information to be of an appropriate standard for their purposes, and will be unlikely to use the service again if they discover otherwise. Guptill and Morrison (1995) describe data quality as consisting of: lineage, positional accuracy, attribute accuracy, logical consistency, completeness and temporal accuracy. These elements have been incorporated into the framework guidelines and framework data set compliance auditing criteria of many nations. For example Somers (1997) documents the guidelines for the US NSDI and Nairn (2000) the ASDI guidelines.

Whilst issues of content, extent, custodianship, format, metadata, standards and access can all help to ensure quality data, of prime concern to a mobile user are the issues of spatial and attribute accuracy, currency and logical consistency. Without some standard or guarantee for these elements, LBS would offer little value to end users.

3.8 Framework to Facilitate Wireless Applications

3.8.1 SDI Requirements

As noted previously, the specifics of wireless access and dissemination of spatial data to a diverse user group presents many challenges. As a result, the requirements for an SDI in this environment (identified in the previous section) have been synthesised below for each component and presented graphically in Figure 3-6. The matrix of requirements is not intended to be definitive, but it does form a foundation for an expanded SDI that supports LBS.

The access component is required to provide an efficient request-response turnaround for the service and be capable of meeting the demands of multiple simultaneous users without significantly degrading service speed. Whilst these issues are relevant for all SDI, they are regarded more highly by users in the wireless environment. Associated with the access component are the issues of information presentation and cognition. Information should be presented in a way that can be quickly and easily read and understood given that mobile users are likely to be completing other tasks simultaneously. Interaction methods (including personalisation features) also form part of the access component's requirements.

Generic policy requirements are more difficult to define than the requirements for the access component, as they are likely to vary more widely for each LBS implementation. Four broad requirements have been identified; firstly guidelines on the knowledge of user's location and/or activities, and use of this information are required. Secondly, provisions for informing users of the validity, accuracy and currency of the information presented are required. Thirdly, unlike other SDI implementations, the decision making process undertaken by a mobile user must be completed rapidly, and even in some cases dynamically; by allowing users to customise services, this may be able to occur more rapidly. Finally, pricing models will need to be determined on a case by case basis. In some instances a subscription model may be appropriate, in others a pay per use model may suffice.

The standards component requires seamless integration and interoperability between data sets. As is the case with other SDI this may include data of varying resolution and granularity. Most critically, expressions of data quality (including currency, and precision) are required.

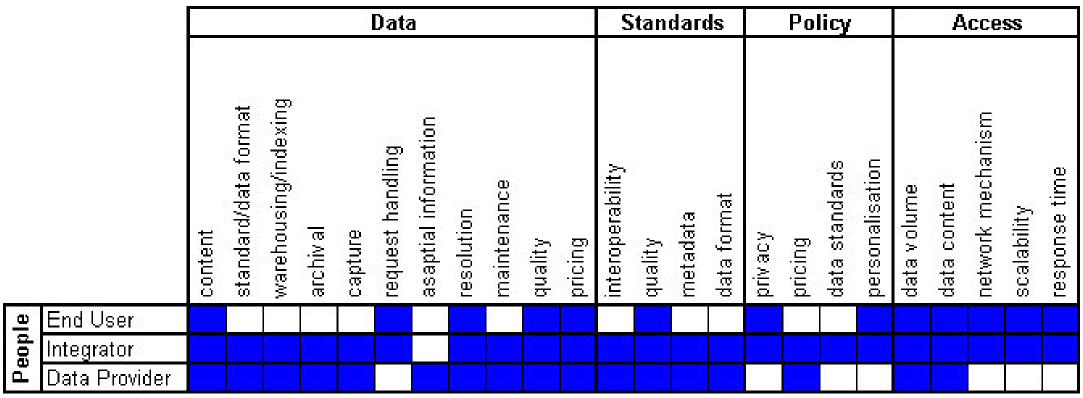


Figure 3-6 SDI requirements for each of the SDI people categories

3.8.2 User Environment

To date, the SDI user environment has been predominantly focussed on the public sector. Increasingly the private sector are realising the benefits that can be obtained by the data collaboration and sharing practices encouraged by SDI.

The three people categories identified in Section 3.7.1 describe the three actors and their corresponding roles within an SDI. Typically the public sector will play the role of data provider, and this would be no different in an LBS SDI. For example, the base data sets of road network and cadastre are the responsibility of local and state governments respectively. However, this does not exclude the private sector from the role of data provider. In fact, the navigational requirements of many LBS data sets will mean that a high proportion of data will be provided by the private sector through the value adding of navigation and additional attributes to base state and local scale data sets.

The data integrator role, following current trends, is expected to be taken up by private industry. Organisations will continue to develop easy to use applications for end users. An environment that facilitates LBS application development by providing access to a repository of appropriate data sets governed by associated policies and standards would relieve developers from having to invest significant time and resources in establishing arrangements to obtain data or implementing independent data capture regimes.

Finally, the role of end users encompasses using LBS to solve common problems related to their location and either some destination or target object. For example, this category could include: people interested in getting from one location to another, learning more about a particular area, finding a central meeting place for a dispersed group of friends; managers tracking a mobile workforce; clients tracking shipments; etc. The challenge is to develop applications that anybody, regardless of their spatial information knowledge or training, can use to solve their everyday problems.

3.9 Conclusions

In response to the increased importance that has been placed on information over the last half century, many initiatives have emerged to share data and benefit from the combined resources. In the spatial information industry these initiatives have been labelled SDIs.

Evolving as a result of a need to improve access to spatial data sets, technological developments have enabled SDIs to become a reality, servicing a wide range of users (from spatial information experts through to the general public).

Having presented the background for both SDI and LBS, and identified how SDI could operate in a wireless environment, the next chapter brings the ideas of LBS and SDI together further and seeks to explain and justify the adopted research method.

Chapter 4 Research Design

Building on the theories of SDI and LBS, as presented in Chapter 3, this chapter describes the research methodology adopted to determine how the SDI model needs to adapt in order to support wireless information access and dissemination.

4.1 Introduction

Introduced in Chapter 3, LBS encompass many of the issues that have traditionally been a focus of SDI research. It is this synergy that provides the justification for examining the SDI model as a basis for LBS. The correspondence between the two concepts is explored further within this chapter, and leads on to the hypothesis generated for this research. The method by which the hypothesis was tested is also presented and justified.

4.2 SDI and LBS Similarities

Relying on a range of integrated data sets (both spatial and non-spatial), LBS must extract relevant portions of these data sets and present them to users in an appropriate form. In order to achieve this, suitable policies for data use must be in place, and communication methods for wireless information transmission defined. From an LBS perspective, the essential elements are the people (encompassing the diversity of producers and users of spatial data), and the data necessary to support the service (in particular its currency, completeness and integration). For the data to become useful information it is necessary to have in place networks for access, together with policies governing use, and standards relating to the quality of data, and its integration. These broad requirements parallel the five SDI components of people, access networks, policy, standards and data (refer to Figure 3-2).

The cohesive nature of the model components requires a collective examination when determining the SDI requirements in the context of LBS. Focusing on any individual component in isolation could lead to a fragmentation of the infrastructure due to the strong coherence and coupling between the components. To demonstrate this reliance of components, consider the issue of privacy in the context of LBS. Within the policy component, specifications on the tracking and use of mobile device positioning information would be required to appease end users of their privacy concerns. At the same time, the technical standards component would have to ensure that the quality of data (including the positioning accuracy) provided to users was maintained to a level sufficient for the service.

Although SDI models have proved sufficient for spatial analysis, long term planning and decision making, as well as a range of other (relatively static) modelling purposes, mobile services place new requirements on the use and delivery of geographic information. This arises from the properties of LBS which can be described as being concerned with:

- information exchanges that are time and space critical;
- the ability to support dynamic spatial decision making (with the consequent need for immediacy and flexibility);
- information that is proximity critical (the closer you are to an activity, the more important it is to know about that activity);
- information display on a device of limited affordance and screen real estate; and
- the competition of tasks and events whose outcome may influence subsequent decisions (such as changes in weather, tasks taking longer to complete than expected, etc).

These issues relate to the 'user centred' dissemination of information, but they can also be linked to the technical SDI components as summarised in Table 4-1.

Table 4-1 SDI requirements in light of LBS delivery

Component	Requirement
Access:	Speed or scalability of service
	Ease of production of information
	Ease of consumption of information
	Methods of interaction and personalisation
Policy:	Knowledge of location of people and/or activities
	Correctness of information
	Critical nature of decision making
Standards:	Greater integration and interoperability
	Quality of data (currency, precision)
	Varying resolution and granularity of information

Thus the demands and requirements inherent in the mobile nature of LBS users are highlighting limits to the current SDI model. While the generic SDI principles of people, access, standards, policy and data are still of prime importance to LBS, more detailed definitions of each of these components is required to meet the challenges of the mobile, wirelessly connected end user.

4.3 Research Questions

The background theories of SDI and LBS discussed in Chapters 2 and 3 respectively, and their synergy identified in the previous section, emphasised several areas worthy of investigation surrounding mobility, cognition and information access.

Although not embraced as rapidly as initial predictions suggested, the mobile Internet is providing an information channel specifically suited to mobile users. The nature of the mobile environment (encompassing portable handheld communication devices, multi-tasking users, and available communication media) has required compromises to be made between device size and functionality. The idea behind the mobile Internet is not to replicate the multimedia rich environment of the fixed Internet, but rather to allow people to access the specific information that they need, when and where they need it. A resulting necessity to reduce information quantities is partly overcome by incorporating the location information of the mobile user.

Examining the needs of mobile users in terms of the range and type of information they would find useful is critical in the successful development and deployment of an LBS. Many studies have reported that direction and navigation information are regarded as being highly sought after by mobile users (Ericsson 2002; Bourrie 2000). While technically possible, providing spatial information to mobile users adds another dimension in functional complexity; special consideration into how this information can best serve the user is required. This raises questions such as:

- To what extent do (or will) the fields of spatial information and mobile services intersect or interact? What are the dependencies?
- What is the potential for mobile users to access spatial data?
- What is the social impact of providing spatial information to mobile users?
- What opportunities/hindrances do spatially enabled handheld applications offer to their users?

- How can mobile users take advantage of real-time data?
- What are the semantics of spatial queries?
- How is spatial knowledge encoded/structured/accessed cognitively during navigational tasks?
- How do users plan routes, follow or modify plans and orientate themselves?

Many of these issues relate to human cognition, geographical perception and usability of handheld computing services, however they all relevant to the provision of spatial (and associated attribute) information in the form of a service. The fundamental policies and relationships required to provide wireless spatial services is currently lacking. Considering these aspects, the need to develop an integrated architecture for real-time, location based, mobile decision making is evident.

4.4 Hypothesis

As a result of the background research into SDI and wireless application capabilities, the following hypothesis has evolved:

> Expanding the SDI model in terms of potential user categories for wireless LBS will identify additional features that support wireless, real-time, spatial decision making.

The following chapters of this thesis aim to illustrate the testing of this hypothesis through the development of an integrated deployment architecture for an LBS. A practical development approach was adopted to assess the technical aspects of the architecture and to explore the possibilities and limitations for applications developed using current technologies. Evaluating the prototype application in terms of the SDI components helped to clarify the augmentations necessary for the SDI model to support wireless, spatial applications.

4.5 Method

The method adopted for this research comprised conceptual model evaluation and clarification through both theoretical analysis and practical development in order to test the hypothesis. The components of the SDI model were evaluated in terms of their suitability to wireless information access and dissemination from a theoretical perspective in Section 3.7. While relevant to LBS, the SDI model currently lacks specification of the unique characteristics associated with wireless communication. In order to verify the additional requirements for each of the SDI components identified through the initial theoretical evaluation (refer to Section 3.7), and determine any new requirements necessary for wireless spatial decision making, a prototype LBS application was developed. The application area of a public transport information/advisory system was selected, explained in greater detail in Section 4.7, due to the spatial and temporal dynamics of both public transport patrons and the public transport vehicles themselves. The application was a functional prototype with limited data sets (only Melbourne metropolitan trams were implemented, and a subset of the full weekly timetable utilised).

The prototyping technique is regarded as highly useful in the software engineering domain and is commonly employed to gather and clarify requirements (Pressman 1997 p.33). For the purposes of this research, the requirements under consideration were not solely related to the application but included the broader perspectives of the supporting infrastructure. Jacobson et al. stress that the aim of prototyping is 'not to create a product, but to emphasise and demonstrate certain properties of the intended system' (1993). This was indeed the case for this research, with the aim of the prototype being:

(i) to identify expansions to the current SDI model components; and
(ii) to examine the usability issues of information delivery LBS.

Evaluation of the prototype (and the accompanying model) was conducted using two techniques, a walkthrough evaluation and a usability evaluation, in light of the research objectives (refer to Section 1.4). The evaluation techniques are described in the following sections.

4.5.1 Walkthrough Evaluation

The first evaluation technique focused on the SDI model and aimed to gather feedback and input into the requirements of the model. This method is referred to as the walkthrough evaluation since participants were involved in a semi-structured demonstration of the application (guided by a facilitator) that occurred independently of user mobility; participants were not required to physically follow the instructions suggested by the application, but rather were encouraged to conceptualise use of system in the real world. The demonstration was semi-structured to minimise errors encountered with the application (as a result of the limited data available for the system) and to ensure that the full capabilities of the application were observed.

For this evaluation, a purposive sample of representative participants for each of the SDI people categories identified in Section 3.7.1 (data providers, integrators and end users) were invited to take part in the application walkthrough. The evaluation process involved providing participants with an explanation of the research project and its aims, followed by a semi-structured demonstration of the application and explanation of its intended use. Following the demonstration, participants were invited to complete a questionnaire detailing their computing experience, spatial experience, opinions of the application and SDI related issues. Participants were requested to keep in mind that the focus of the research was on the underlying technologies enabling the application, rather than the usability and interface of the application.

To ensure that the individuals invited for participation covered the range of SDI people categories they were initially pre-categorised based on their organisation. Those initially identified as data providers or integrators were asked to clarify which SDI People Category they believed their organisation or department belonged to; those initially identified as end users were not given this choice. As a result, two marginally different questionnaires were distributed to the participants depending on their *a-priori* SDI People Category. Section 10.1, Appendix A, contains a copy of the questionnaire given to *a-priori* classified data provider and integrator participants. End user participants were given the same questionnaire, however Question 15 was removed.

4.5.2 Usability Evaluation

The second evaluation method was intended to gather information about the usability of the system and required a small sample of end users to perform a series of real tasks with the application (refer to Section 10.2, Appendix B, for the task descriptions). The use of structured tasks and scenarios for this evaluation was necessary due to the limited data used in the system. Evaluations were conducted for two contexts: in the real world (or field); and in a specialised usability laboratory. The same tasks were used for each context and each participant was evaluated in only one context. To record and document the evaluation, each participant was observed by three evaluators – a facilitator (who interacted with the participant, providing guidance with the tasks and encouraging them to 'think aloud' by verbalising their thoughts and actions) and two observers (one capturing the participant's interaction with a video recorder, the other taking notes and providing technical support, if required). At the conclusion of each task, participants were presented with a questionnaire designed to measure user performance and satisfaction (refer to Section 10.3, Appendix C). At the conclusion of the evaluation, participants were also invited to complete the walkthrough evaluation questionnaire (see Section 10.1, Appendix A). This evaluation was developed and conducted in conjunction with colleagues from the Department of Information Systems at The University of Melbourne.

4.5.3 Evaluation Briefings

In both evaluations, the participant briefing was a general explanation rather than specific training in the use of the system. This was deliberately performed in the hope of eliciting a wider range of feedback. However, it was expected that some of the feedback would relate to design and implementation decisions that were beyond the scope of the intended responses. This was expected to be particularly evident in the usability evaluation, considering that the prototype was designed to demonstrate ideas and theories, rather than to be a robust application for users.

4.5.4 Questionnaire Analysis

Following both of the evaluations the questionnaire responses were analysed to identify SDI requirements from the perspectives of each of the SDI people categories, facilitating the expansion of the SDI model. Responses from participants within the end user category were obtained from both the walkthrough and usability evaluations (field and laboratory) accommodating a range of user mobility contexts.

4.6 Justification of Method

The research method described above could be classified as an exploratory or normative case study approach since it intended to not only gather facts regarding a single phenomenon in its context, but also to identify areas of the object of study (in this case the SDI model) that required improvement, including what these improvements should be (Schloss & Smith 1999; Yin 1984). The choice of a case study approach over an experiment, survey or archival analysis primarily lies in the type of research questions posed, the resulting hypothesis and the focus on contemporary as opposed to historical events (Yin 1984). Like many other research projects, this research was based on an existing model that has been an appropriate representation to date. Introducing the model to a new emerging environment – wireless communication – was ideal for the case study approach and highlighted that while the basic model was still valid, a few areas required improvement.

Using a practical instrument as the focus of the case study introduced a tangible focus to the SDI model. Despite the generic and long standing principles underlying SDI, relatively few practical implementations exist and those that do typically fall in the government domain rather than the private sector. Considering the growth of the LBS market in the private sector (not overlooking the initial input in this field from the public sector through emergency service mandates), identifying a specific area (public transport) and developing a working application allowed evaluation participants to experience some of the SDI principles in action, and encouraged exploration of SDI based LBS ideas.

Since the main objective of the study was to investigate SDI requirements in terms of facilitating spatial decision making in the wireless environment, it seemed appropriate to elicit participation from practitioners in the spatial information industry. The target population of the research included participants representing each of the SDI people categories. Participants did not require any prior experience with the application, LBS or SDI and were selected to encompass a range of computing and spatial abilities.

Potential participants for the walkthrough evaluation were identified through existing links with the both the author and the Department of Geomatics and thus formed a purposive, non-random sample. Participants were initially allocated to one of the SDI people categories to ensure an even distribution across the categories. It was identified early on that the participants were potentially biased by their familiarity with the issues faced by the spatial information industry, as well as by their relationship to the author or Department. In order to overcome (and potentially verify) the bias associated with this sample, an independent sample was also asked to complete the same questionnaire. This independent sample comprised the participants involved in the usability evaluation and, whilst recruited through their links to the Department of Information Systems, they did not have any links to the author or the Department of Geomatics. The nature of the usability evaluation required that participants had some familiarity with the tram system of Melbourne and whilst potentially biased due to their knowledge of participating in and undertaking usability evaluations, they provided a relatively random sample of spatial expertise – although this was not formally measured. Usability evaluation participants were all classified as end users, and thus it was only meaningful to compare the results from participants classified as end users from both evaluations.

As touched upon previously, the primary research instrument chosen was a questionnaire. This decision was based on the natural synergy with the research style; revising a model, particularly through a prototype demonstration, is a focused problem domain for which questions regarding facts or easily definable elements can be developed well in advance. Questionnaires also offer the benefits of being highly standardised, rapid to execute and allow a level of quantitative analysis of the responses (in particular quantifying the relationships between variables), all of which are more difficult to achieve with an interview. In the usability evaluation, direct observation of the participant's interaction with the system was also employed.

The number of participants selected for each evaluation was intentionally kept small given the available resources and studies on usability evaluations indicating that 80% of a web site or product's functional deficiencies can be found with as few as five participants (Nielsen & Landauer 1993). While this figure has been disputed (refer to Spool & Schroeder 2001; Woolrych & Cockton 2001) it is still the common starting point for usability evaluations based on the return on investment. For these reasons five participants were initially selected for each of the field and laboratory usability evaluations. Given that the participants were completing structured tasks, the likelihood of users identifying the same usability issues was fairly high. The two contexts of the evaluation provided a comparison on the issues identified and the number of users required to identify those issues. While the walkthrough evaluation was not a usability evaluation, five representatives of each of the SDI people categories were also initially selected. As this evaluation progressed, additional end user participants were added to the sample to balance the sample size of this category with that of the usability evaluation.

Ethics approval was obtained and granted for the evaluations in accordance with the University of Melbourne's Code of Conduct for Research.

The following sections justify the use of the public transport application domain, explain the components of the system and the evaluation procedures in more detail.

4.7 Case Study - Public Transport Information System

One of the objectives of this research was to use a practical approach to explore and extend the understanding of SDI requirements. The application area of a public transport information or advisory system was chosen for this purpose due to the spatial and temporal dynamics of both public transport patrons and the public transport vehicles themselves. Additionally, public transport networks change spatially, topologically and temporally and systems are required that can cope with mobile, dynamic decision making (Costelloe, Mooney & Winstanley 2000), that accommodate the task of activity scheduling (Huisman & Forer 1998) and that take into account route length, travel mode, time, and frequency of mode changes. Achieving all of these requirements immediately in one system was a difficult task, and thus a set of phased implementations of increasing functional complexity was proposed. Ultimately, the prototype would enable users to plan trips using the Melbourne metropolitan tram network. Rather than implement all of the Melbourne public transport modes into the system, using only one mode, trams, was deemed to be sufficiently complete for the purposes of this research. While there are similarities between all the public transport modes operating in Melbourne, trams are most commonly associated with pedestrian travel at the beginning and end of journeys (rather than other vehicles), offer a frequent service within the central business district of Melbourne (providing complexity for the routing algorithm) and have an integrated vehicle positioning system (although this was not directly used in the prototype).

The strong user focus and the time critical nature of this service lends itself to Jacobson's method of object-oriented software engineering (OOSE) (Jacobson et al. 1993). The OOSE method involves the formation of models that capture the actors of the system and their behaviour for each of the design stages. As the method name suggests, the models are made up of objects representing real world entities. This is a natural way for people to describe their environment, therefore the semantic gap between the models and the real world is relatively small.

Following the OOSE approach, the software development process adopted a sequence of requirements specification, analysis, design, implementation and testing. As is noted by Henderson (1991) and Jacobson et al. (1993) this process is usually cyclic or incremental in nature following the development of the product – each implementation refines the analysis and design stages through evaluation and testing of a completed version (refer to Figure 4-1). In the context of this research, this successive version development was anticipated to lead to a more informed view of SDI requirements.

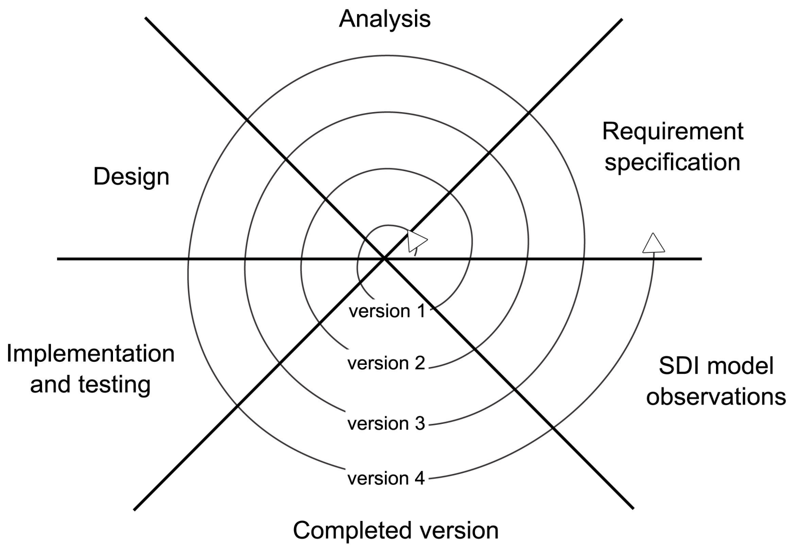


Figure 4-1 Components of design feeding through to implementation and observations of SDI requirements (adapted from Jacobson et al. 1993 p.72)

The incremental development strategy allowed the problem of constructing a public transport information system to be tackled in smaller, more manageable portions of increasing complexity. In addition, it was expected that each version would reveal unique features related to the requirements of the underlying infrastructure and enable exploration of the interfaces between the SDI components. A summary of the prototype versions is given in Table 4-2, and an example of the SDI components expected to be explored through the first version of the prototype are shown in Figure 4-2.

Table 4-2 Proposed prototype implementations

Version	Functionality/Description
1	Tram route finder (from one tram stop to another)
2	Tram route finder (from origin street intersection to destination street intersection) with pedestrian navigation to first stop, and from last stop (where necessary)
3	Tram route finder (from origin street intersection or GPS position to destination street intersection) with integration of real-time tram timetable information

		Data	Standards	Policy	Access
People	End User				
	Integrator				
	Data Provider				

Figure 4-2 Dark grey boxes represent the SDI elements expected to be explored through version 1 of the prototype

Information systems such as the proposed prototype fall within the realm of Intelligent Transportation System (ITS) strategies, mainly from the perspective of providing efficient service and ensuring safety of users through the management and provision of information.

4.7.1 Intelligent Transportation Systems

Public transport infrastructures around the world are often perceived as inadequate and unreliable, offering inconvenient services and routes. Recently, ITS technologies have been introduced to overcome some of these impressions.

Adopted internationally with mandates of reducing traffic congestion, environmental damage and increasing safety and security, the national benefits of ITS solutions are reported as extremely high; a study conducted by Intelligent Transportation Systems Australia determined that the benefit to the nation of implementing an ITS was over $14 billion (McIntosh 1999). Irrespective of the technologies involved, the effectiveness of ITS solutions relies on community uptake.

ITS strategies, relying on information and communications technologies, are intended to improve safety, cleanliness, security, efficiency and availability of transport services (ERTICO, ITS Asia-Pacific & America 2002). These goals are achieved through 'information- and infrastructure-based approaches' (US Department of Transportation n.d.). Typically regarded as services for private vehicles (for example Forward Collision Warning, Blind Spot Monitors, Adaptive Cruise Control, Lane Departure Warning, Night Vision, Assisted Steering and Pre-Crash Safety Systems (ITS Australia n.d.)), ITS strategies and visions encompass all facets of transportation. Specifically for public transportation, ITS strategies focus on making public transport more convenient and affordable. Categorised according to the major ITS goals, Table 4-3 identifies the specific visions or improvements predicted for public transport by ITS organisations worldwide. Consideration as to whether each vision would be supported by either an information or infrastructure (in terms of physical transport networks and systems) approach has been made. Information approaches (including access, monitoring and documentation) are expected to play a significant role in progressing ITS developments for public transport. The effectiveness of these visions is therefore fundamentally reliant on ensuring that all public transport users have access to information.

Table 4-3 ITS theme applicability to public transport
(adapted from ERTICO, ITS Asia-Pacific & America 2002)

ITS Theme	Public Transport Vision or Impact	Approach
Security	Improve personal security of public transport patrons.	Information/infrastructure
Mobility and access	Assist travellers in planning and making trips using the best and most convenient combination of transport modes.	Information
	Simplify payment methods for fuel, tolls, public transport fares, parking with a single electronic payment mechanism.	Infrastructure
	Assist transport managers in providing services that are reliable and responsive to users needs.	Infrastructure
Environment	Improve reliability, effectiveness and attractiveness of public transport services, and as a result accelerate use.	Infrastructure
	Provide better information on public transport schedules and connections.	Information
	Help public transport patrons stay in touch with family and friends whilst travelling.	Information/infrastructure

Technology convergence and high adoption rates of mobile communication devices means that it is now possible to provide public transport advice to passengers anytime, anywhere. Internet and mobile-Internet protocols are helping to make the delivery of such services a reality. The intelligence and currency of advice remains a challenge.

4.7.2 Information Delivery Paradigms

Two different paradigms exist for serving information over the Internet to mobile users (refer to (Manolescu & Santamarina 2002; Starner 2002)). The 'thick-client' approach distributes processing to the client, or user device. The alternative approach, referred to as the 'thin-client', relieves the client device from processing (which is instead conducted on the server) and enables it to act solely as a presentation or visualisation interface. There are inherent strengths and weaknesses in both models and the choice between the two ultimately lies in the type of application being developed.

In the thick-client model, a large quantity of data is initially loaded onto the client device, in addition to programs for viewing or processing the data. In some cases the user may be required to download and install additional plug-ins for their browser to facilitate analysis and interactivity. For widespread public transportation advice this approach is relatively undesirable, given the range of devices and their typically limited memory and processing capabilities. The alternative thin-client approach places most of the responsibility for analytical data processing onto the server computer and utilises the client computer merely as an interface to the data.

It could be argued that many components of public transport tracking and advisory are static (e.g. vehicle infrastructure routes, scheduled timetables and general contextual information) and therefore these should not need to be transmitted to the client each time a request is made. However in order to make the information generally accessible and provide dynamic and real-time information, a thin-client approach would be more versatile, and therefore has been adopted for this research. Additionally, the limited bandwidth available for wireless communication, and differences in device processing capabilities also support the decision for a thin-client approach. A number of existing public transport information systems have also adopted this approach as demonstrated by the systems described in the next section.

4.7.3 Existing Public Transport Information Systems

The notion of providing public transport information to Internet users is not particularly new, nor is it unique. Many transport operators around the world have invested substantial resources in developing applications that will improve acceptance and use of transport systems. While many applications have been developed for the fixed line Internet, a small number of public transport providers have kept up with the trends in technology adoption and developed applications for the mobile Internet. Table 4-4 lists some of the more widely advertised transport services for WAP enabled mobile devices.

Europe is heavily involved in these types of services, and despite the difficulties in differing telecommunications networks and protocols in the United States of America, public transport providers there are seeing the value in providing up to date, real time transport information to their customers. Despite Australia having a mobile phone penetration rate of almost 70%, ranking it fourth in the Asia Pacific region in terms of market development (Australian Communications Authority 2002), Australia is not as far ahead as Europe and the USA in the development of mobile data services. Accommodating the available network and phone capabilities of Australians, two public transport operators have developed SMS alert systems to warn registered clients about delays to services (refer to Adelaide Metro 2003; Connex Melbourne 2002). SMS public transport trials have also been conducted in Perth (Transperth 2003).

In response to the evolution of purposes of online transit information systems (from static information dissemination to interactive communication and online transaction), Peng and Huang (2000) define a taxonomy of transit information systems according to function and content (refer to Table 4-5). Using this model, information content can range from general, static information through to real-time information (including vehicle positions and delays). The function level and interface of transit information systems can span simple web browsing at the lowest level through to customised information delivery and online ticket transactions at the highest level. By assigning increasing integer values to each function level, and increasing alphabetical characters to each content level, Peng and Huang's framework is a useful means by which to classify transit information systems.

The systems identified in Table 4-4 have been analysed using Peng and Huang's taxonomy (Table 4-5) and are shown in Table 4-6. Typically, existing WAP transit information services offer limited text and static graphic functionality, however they do cover the full range of content from general through to real-time information. Functionality is predominantly limited by device display capabilities and WAP technology which is designed as a text based interface. As Multimedia Messaging and enhanced browsers emerge for networked portable devices, the range of functionality offerings will improve. Despite the current technological limitations, a number of services have expanded on the text delivery, by offering limited forms of information customisation and delivery. The independent and isolated nature of the development of these applications, in addition to a lack of current, affordable, readily accessible data sources are contributing to the limited functionality of these systems. The lack of infrastructure supporting these applications also reinforces the justification of this research.

As described in Section 4.7, full functionality of the prototype system was implemented iteratively across the three versions. Initially relying on static information with restricted searching and static graphic images, the first version of the prototype could be classified as a B1 service. The final version incorporating real-time content with customised information delivery could be classified as a D1 service – inline with the current WAP services. While offering additional functionality, services with interactive map-based search query and analysis functionality (level 2) are currently difficult to develop given the display and interaction limitations of handheld devices.

Table 4-4 Examples of Web and WAP based public transport information systems

System	Location	Application	Launched	Description
a	Seattle, Washington USA	MyBus (Web: http://www.mybus.org/) (WAP: http://www.mybus.org/wml/)	September 2000	Provides real-time bus information to WAP devices (also have a web and Palm version). (Murakami 2003)
b	London UK	Transport for London (WAP: http://wap.tfl.gov.uk/) (Web: http://mobile.tfl.gov.uk/)	February 2001	Journey planner, departure board and travel news services for WAP devices. (Lewell 2001)
c	Glasgow UK	Glasgow Night Bus (WAP: http://www.tagtag.com/gla-bus/) (Web: http://freespace.virgin.net/andy.preece/publictransport/nightbuses/index.htm)	February 2003	Timetable information for night buses in Glasgow. (Preece 2003)
d	Barcelona Spain	Transports Metropolitans Barcelona (Web: http://www.tmb.net/eng/tmb_al_teu_movil/wap.jsp) (WAP: http://wap.tmb.net/)		Categorised into: timetables for particular bus and train routes, ‘I want to go to…’ and ‘How are you getting here’, this service provides route planning and static timetable lookup functionality, as well as general travel information including ticket descriptions and pricing. No transaction capability is provided.
e	Germany, Zurich, Switzerland Austria Poland	(Web: http://www.hacon.de/hafas_e/wap.shtml) Deutsche Bahn (WAP: http://wap.bahn.de/) Zürcher Verkehrsverbund (WAP: http://wap.zvv.ch/) Österreichische Bundesbahnen (WAP: http://wap.oebb.at/) Polnische Staatsbahnen (March 2001) (WAP: http://wap.pkp.pl or Web: http://www.rozklad.pkp.pl/cgi-bin/new/query.exe/en)		A static timetable train trip planner with advanced query functionality (allows stop numbers or street names to be used in the search).
f	UK	ACIS Live (Web: http://www.acis.uk.com/technology/wap.asp) (WAP: http://wap.acislive.com/)		Real time bus arrival and departure times for the United Kingdom.
g	UK	National Rail - Kizoom Personal Travel (Web: http://www.nationalrail.co.uk/planmyjourney/time_table/journey_requirements.asp http://www.kizoom.co.uk/railtrack/kizoom_info.html http://www.kizoom.com/products/our_services.html - good listing of other WAP services) (WAP: http://mobile.nationalrail.co.uk/)		Timetable and real-time departure information for Britain’s National Rail Network, with additional services planned for the future (National Rail n.d.).

Table 4-5 Taxonomy of online transit information systems (Peng & Huang 2000 p.411)

			Functionality				
			Web Browsing	Text search, static graphic links	Interactive map-based search, query and analysis	Customisation and information delivery	Online transaction
			0	1	2	3	4
Content	General Information	A	*A0*	*A1*	*A2*	*A3*	*A4*
	Static information	B	*B0*	*B1*	*B2*	*B3*	*B4*
	Trip itinerary planning	C	*C0*	*C1*	*C2*	*C3*	*C4*
	Real time information	D	*D0*	*D1*	*D2*	*D3*	*D4*

Note: The values in the body of this table are used as a shortened form to refer to a system's functionality and content level. Numbers increase with functionality and letters progress with improved content levels.

Table 4-6 Categorisation of systems from Table 4-4

			Functionality				
			Web Browsing	Text search, static graphic links	Interactive map-based search, query and analysis	Customisation and information delivery	Online transaction
			0	1	2	3	4
Content	General Information	A	c	d, b			
	Static information	B	a*, c	a*, b, d, e, f, g			
	Trip itinerary planning	C		b, d+, e, f, g			
	Real time information	D		b, f, g		b-	

Note: The small letters in the body of this table refer to the systems described in Table 4-4.
Legend:
* – functionality expected from description (could not be thoroughly tested due to problems with the service)
+ – functionality exceeds standard description
- – functionality supported, but not fully in relation to the description

4.7.4 Prototype System Components and Architecture

The public transport information system prototype encapsulate the dual tasks of planning a journey, and supporting navigation in 'following' a planned route. Both these tasks require delivery of potentially complex geographic information at a range of scales (from the broad scale of journey planning which requires a conceptual view of the entire region encompassing alternate transport mediums, to the fine scale in portraying landmarks and cues in the immediate vicinity of the traveller). Typically in these contexts, users require information that is centred on their location rather than generalised data covering a large geographical extent. Extracting the relevant portions of data sets and presenting them in an appropriate format is a necessity and a challenge for LBS developers.

In order to develop this type of system, a number of components are required (as shown in Figure 4-3). Users, interacting with a handheld device, require access to the route finding application that is responsible for calculating an optimised solution to the user's routing request, from an origin to a destination. The route finding application needs both spatial (tram network, tram stop) and attribute (scheduled timetable, real-time timetable) data in order to form potential routes, analyse their suitability and decide on an optimal solution. In order to access the application, users need network or internet connectivity for their device. Additionally, a positioning service is also required to locate users and assist in information filtering for the route solution.

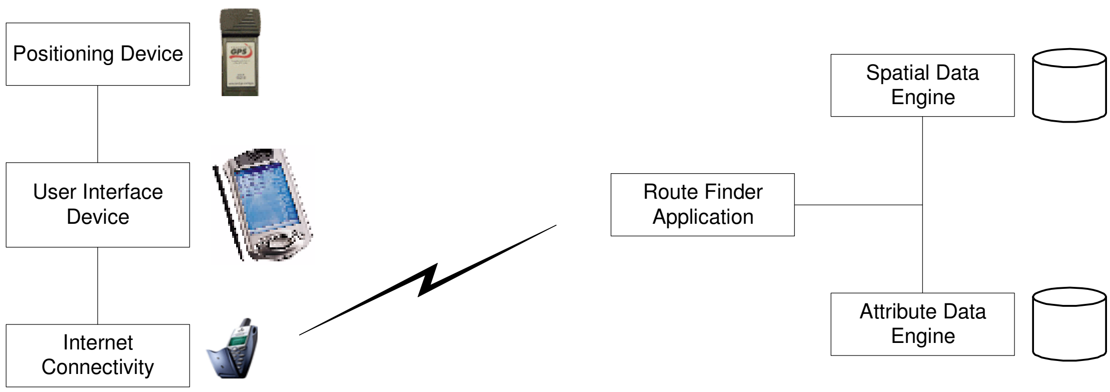


Figure 4-3 System components (high level view)

The prototype was developed as a WAP application for the mobile Internet and is described in greater detail in Chapter 5.

4.8 Questionnaire Design

The SDI model evaluation questionnaire was designed to gather information from a range of participants across the SDI people categories. Organisations involved in data provision (capture and preparation) and spatial application development were identified within the private and public sectors of the Victorian spatial information industry and invited to participate in the study. All ten organisations contacted agreed to provide input to the research (many offering multiple participants), and questionnaires were returned by all but one organisation.

The questionnaire was structured in five sections as shown in Table 4-7.

Table 4-7 Questionnaire Sections

Section	Purpose
1	Personal details (including gender, age and occupation of participant)
2	Computing/technical experience
3	Spatial experience
4	Application feedback (including SDI requirements)
5	General comments

The first three sections were designed to assist in the categorisation of participants based on computing expertise, spatial expertise and gender. Section four elicited information about the usefulness of the prototype and the priorities of requirements for each of the SDI components. The attributes of the expanded SDI model were listed along with definitions, and participants asked to rank what they believed to be the top five most important issues for LBS (similar to the one they had just evaluated).

The questionnaire predominantly contained closed format questions. A mixture of multiple choice questions, check lists, rating scales (including Likert Scales) and ranking order was utilised based on each question and the information that it was attempting to elicit from the participant. Refer to Section 10.1, Appendix A for a copy of the questionnaire.

4.9 Conclusions

This chapter brought together and compared the ideas of SDI and LBS, justifying the suitability of using SDI theories for LBS.

To meet the research aim and attempt to validate the hypothesis, a two tiered approach of conceptual model evaluation and empirical development and evaluation was adopted. The empirical development took the form of a prototype LBS application for public transport. Designed to explore the SDI requirements from a practical or technical perspective, two evaluations of the prototype LBS were proposed; a walkthrough evaluation designed to gain input from a range of participants in the LBS value chain (corresponding to SDI people categories); and a usability evaluation designed to gain input from end users.

Having set the framework for the method adopted, the following chapter describes the development of the prototype in greater detail.

Chapter 5 Prototype Development

Expanding on the research design introduced in Chapter 4, this chapter explains in detail the tools and components of the prototype LBS. Intended only as a representative application to demonstrate an LBS application, the assumptions made for the prototype and the limitations of its functionality are also described.

5.1 Introduction

Introduced in Section 4.7, the prototype was developed using OOSE techniques and an incremental process of requirements specification, analysis, design, implementation and testing. This chapter describes each of these processes in more detail.

5.2 Requirement Specification

The requirements stage of application design aims to define the limitations of the system and specify the system's behaviour from the perspective of a user (Jacobson et al. 1993). Understanding potential system users in terms of knowing who they are and what they want to do, facilitates system development (Weiss 2002). The construction of use cases detailing how a user would interact with the system helped to identify the various system objects (described in more detail later and depicted in Figure 5-2) and highlighted the need for careful consideration to be given to issues of human-computer interaction within the mobile environment (Carroll, Kellogg & Rosson 1991).

Interaction with mobile devices is likely to occur in distracting situations. While users typically have immediate goals or objectives driving their interaction with the device, the need for applications to accommodate context and forgiveness is much higher than for desktop applications. Weiss (2002 p.66) compares some representative Web related tasks and how their focus differs depending on the context of use (Table 5-1). These differences in use context needed to be accommodated in the design of the prototype.

Table 5-1 Comparison of desktop and wireless Web use (Weiss 2002 p.66)

Desktop Web	Wireless Web
Comparing prices of flights and making reservations	Checking status of a particular flight
Gathering background on a company, including maps	Getting driving directions to a company – while on the road
Researching a medical condition	Monitoring a medical condition
Reading a movie review and/or watching a trailer	Purchasing a theatre ticket to avoid the line
Analyzing a portfolio of stocks	Placing a trade
Checking a product's availability	Scanning in warehouse inventory

The public transport information system was intended to assist a user in solving the problem of travelling from an origin to a destination using the tram network. This situation is depicted in Figure 5-1. Depending on the origin and destination, more than one tram might be required to complete the journey.

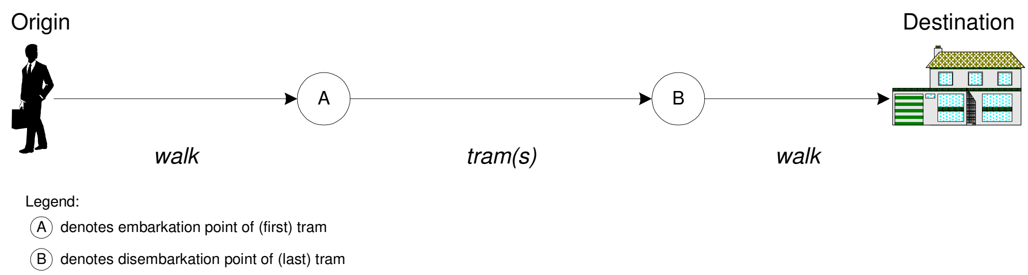


Figure 5-1 The navigation scenario

Examining this scenario, it became evident that a single human user may like to use the system to complete different tasks, and hence interact with the system taking on different roles, at different times. For example they may like to:

- request a route (actor: imminent traveller);
- plan a trip (actor: planner);
- check a particular timetable (actor: planner and imminent traveller); or
- review or confirm trip information during a journey (actor: active traveller).

Using UML syntax, the user interacting with the system in one of these roles is referred to as an 'actor'. In addition to human actors, this system also required a positioning sensor role that, when requested, determines the current position of the mobile device (and hence the user). This process should be initiated when an imminent traveller requests a route, or when an active traveller executes a journey. Figure 5-2 shows the use case model (UML notation) for the actors identified above (represented as stick figures) and their interaction with the various functionalities of the system (represented as ovals). For each actor, individual requirements for the system were developed in an attempt to refine the processes and information flow in greater detail. These are described in the following sections.

The scenarios and user requirements identified in the requirements specification process are coincidently similar to the findings from work undertaken by Kjeldskov and colleagues for the 'TramMate Project' (Kjeldskov et al. 2003). This study involved gathering user requirements for a mobile public transport information service through in-situ behaviour scenarios with business employees who, during a typical workday, need to attend appointments at different physical locations.

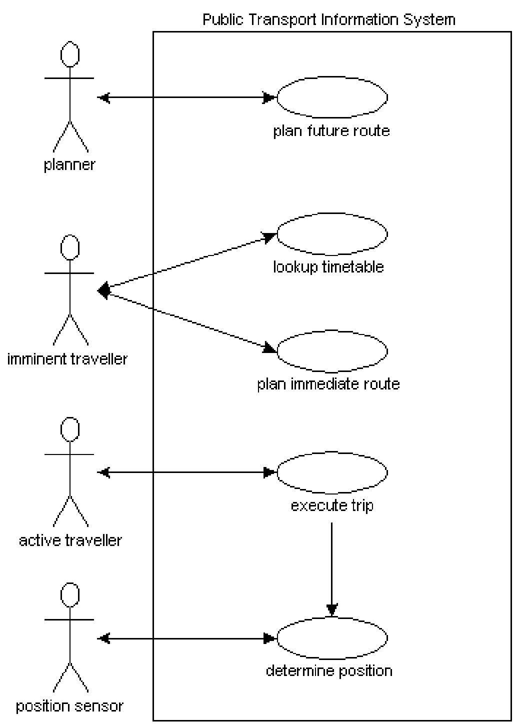


Figure 5-2 Prototype use case model

5.2.1 Active Traveller

The active traveller interacts with the system in a number of ways to gain information regarding:

- confirmation of journey (e.g. stop countdowns until disembarkation);
- updated time of arrivals at the destination and any intermediate change points; or
- route interchanges.

Additionally, this type of user may want to change the journey destination, in which case their role changes to one of an imminent traveller.

5.2.2 Imminent Traveller

The imminent traveller interacts with the system in a number of ways to:

- request an immediate route from an origin to a destination (where the origin is defined by their current position as determined by a positioning sensor, and the destination is defined by a street intersection in the form of two street names and a suburb):
  - departing the origin at a specified time; or
  - arriving at the destination at a specified time.

Depending on their preferences, the imminent traveller may prefer the solution route to be optimised in terms of:

- distance (e.g. shortest route between origin and destination);
- number of route changes (e.g. route with fewest changes); or
- time (e.g. fastest route).

An imminent traveller may be interested in finding out:

- where the closest, appropriate embarkation and disembarkation stops are in relation to their journey origin and destination;
- whether the journey involves a single or multiple tram routes;
- where multiple tram routes are required, a description of the change including where to get off, and where to board the next vehicle;
- how to get to the first embarkation stop from their journey origin (current position); and how to get from the last disembarkation stop to their journey destination; and
- tram departure and arrival times at each stop.

Imminent travellers who are familiar with the tram network, may require an option to

examine a real-time timetable for a particular route.
Options for personalisation (including the ability to store frequently used stops or routes) may also be desirable.

5.2.3 Planner

The planning traveller also interacts with the system in multiple ways, in a similar way to that of the imminent traveller but they do not intend to travel immediately. As a result they may be interested in:

- Investigating route alternatives from an origin to a destination (where the origin and destination are defined by a street intersection in the form of two street names and a suburb):
    - departing the origin at a specified time; or
    - arriving at the destination at a specified time.

The same optimisation options available to an imminent traveller should be available to a planner:

- distance (e.g. shortest route between origin and destination);
- number of route changes (e.g. route with fewest changes); and
- time (e.g. fastest route).

Similarly, options for personalisation (including the ability to store frequently used stops or routes) may also be desirable.

5.2.4 Positioning Sensor

The positioning sensor's role is to determine the position of the mobile device (and hence its user). This position has to be determined to an accuracy appropriate for the application. Position accuracy in the order of 5 – 10m was required for the prototype to successfully provide navigation directions and tram routes to users.

5.3 Analysis and Design

Translating the user requirements into an interface and the underlying algorithms falls within the analysis and design portion of the OOSE lifecycle.

The characteristics of mobile devices and mobile users (described in Section 2.5.2) were kept in mind throughout the development of the prototype, and resulted in a number of specific design decisions for the application. Weiss (2002 p.xi) reinforces these characteristics:

> 'Handheld devices are used by people who are 'on the go', and the devices – as compared with desktop computers – have smaller displays, trickier input mechanisms, less memory and storage, and less-powerful operating systems.'

Development was also initially tailored for the lowest market entry level for Internet enabled mobile devices – monochrome display WAP enabled mobile phones – despite the prototype being developed and tested on an iPAQ™ PDA (one of the higher classes of Internet enabled mobile devices).

A broad range of alternatives exist for the portrayal of journey information, from simple, a-spatial text (Figure 5-3a), through 'geographical text' such as landmark information (Figure 5-3b), to graphical map based solutions (Figure 5-3d). The information representations depicted in Figure 5-3 were developed with the screen limitations of mobile phones in mind. An abbreviated description of the tram routes proposed to complete a journey was devised to maximise semantic value whilst minimising transmission quantities. Figure 5-3a represents a journey solution between an origin and destination, with each line representing one segment of the proposed journey. This journey involves two tram rides. Lines describing a tram trip use the following syntax:

s<stop number to board tram> rt<route number of tram> <direction of tram (I or O)> s<stop number to disembark tram>

where the items enclosed by < > are replaced by appropriate values.

Therefore according to this syntax, the first line of Figure 5-3a suggests boarding the inbound route 19 tram at stop 11 and disembarking at stop 27. Tram route changes (or interchanges) are included as a separate line so that additional information can be obtained about where the interchange occurs, and how to get from the disembarkation stop to the next embarkation stop.

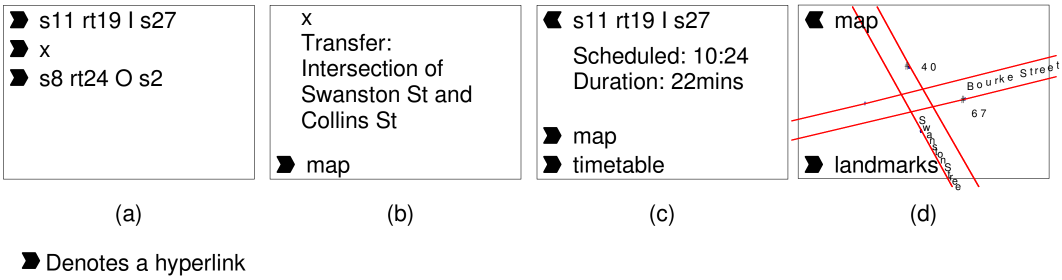


Figure 5-3 Proposed interface (a) raw text, (b) landmark descriptions, (c) route description, or (d) maps

Weiss (2002) identifies that applications must strike a balance between ease of use and ease of learning; ease of use refers to the speed with which tasks can be completed, and ease of learning refers to the intuitiveness of completing a task. The interface proposed for the prototype strove to meet this requirement. Adopting these principles the journey text (such as Figure 5-3a, Figure 5-3c) is abstract, readily remembered, simple to interpret, and would suffice for a user familiar with the tram system. Additionally, description of the environment (Figure 5-3b) can be used to clarify waypoints along the journey. Information of the form shown in Figure 5-3d would require the user to interpret and navigate (using skills in orientation and positioning). It is easy to envisage different environments or use contexts in which each (or a combination) of these would be most appropriate. Indeed information in these forms lend themselves to a hierarchical structuring according to the level of detail and whether the use is planning or executing a journey (for example in the case of planning a journey, the hierarchy may move from a-spatial text, through landmark and route descriptions to maps). Figure 5-4 depicts an example information hierarchy moving from the simplest a-spatial raw text through to graphical geospatial information (maps).

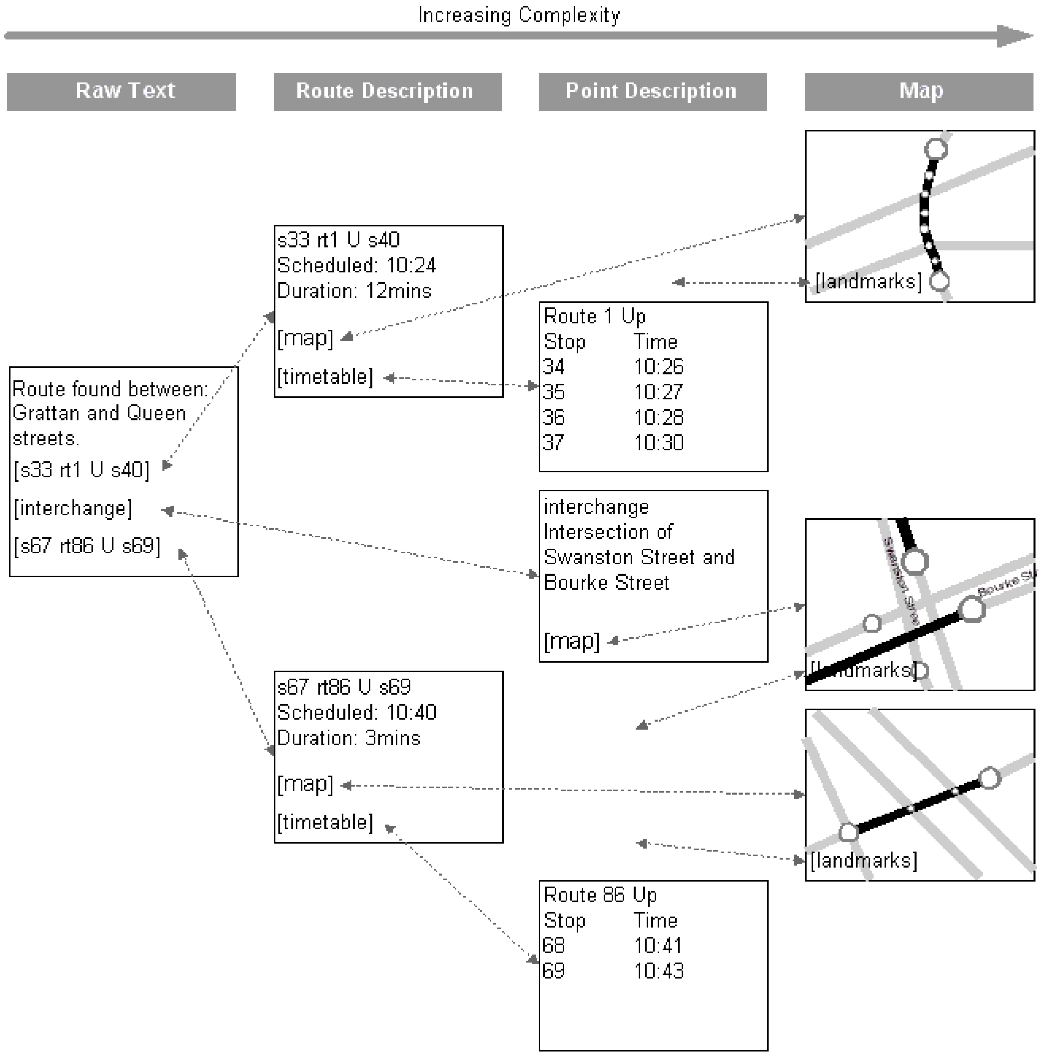


Figure 5-4 Information hierarchy

Interface design and related usability principles are a well researched and documented area, and while Nielsen and Molich's general heuristic principles (refer to Molich & Nielsen 1990; Nielsen 1994) are still relevant to the mobile environment, some revisions are required. A specific set of heuristics for wireless LBS based on the work of Molich and Nielsen is given in Table 5-2.

Table 5-2 The heuristics of good design for mobile environment LBS (based on Molich & Nielsen 1990; Nielsen 1994)

Visibility:	Display the status of the system (inform users what the system is doing), provide alternative actions.
Responsive:	Efficient in delivery and interpretation of information.
Reinforcement:	Confirmation of location (e.g. through landmark information) increases confidence.
Reversibility:	Ability to backtrack mistakes and re-enter data.
Adaptability:	Information presented in a variety of forms, customised to user's geographical knowledge and needs and preferred mode of interaction (e.g. keystroke/shortcuts or stylus). Includes personalisation features.
Predictability:	User control (or system) anticipates information requirements.
Structure:	Organisation of data (e.g. according to task/ level of detail).
Consistency:	Principle of least astonishment and coherence in the operation of keys, menus, etc.
Compatibility:	Follows from previous experience in using similar devices.
Good mappings:	It is possible to determine the relationships between actions and results, between the controls and their effects, and between the system state and what is visible.
Multi-tasking:	Complimentary to other competing tasks.
Economy:	Few steps (keystrokes) in reaching information.
Memorability:	Information readily assimilated or memorised to reduce revisits to device.
Abstraction:	Irrelevant information impairs short term recall
Error prevention:	System error trapping (e.g. through fixed choice menus).
Error recovery:	Support user in recognising/recovering from errors/missing information.
Help or Documentation:	Providing information (on-line and as a manual) in the use of the system.

In the context of this research and the examination of SDI, the interface design focused around these heuristics and a hierarchical information structure (as described above) from simple text descriptions through to two dimensional static maps.

With the analysis of the user requirements and design of the interface structure completed, it was possible to expand the overall system component model (Figure 4-3) into a more detailed description of the system (refer to Figure 5-5). Adopting the principles of reuse and collaboration, existing components suitable for the prototype application were sourced and employed where possible. For example, Sensis™ (one of Australia's leading information, advertising and directories businesses) maintains an extensive geospatial data set with accompanying navigation, mapping and geospatial searching functions known as the Whereis Location Server (Whereis 2002). Capable of completing routing requests between two locations, the Whereis Location Server data is designed for travel by car or foot, and can include public transport routing where data is available. Routing requests can be linked with map requests to indicate the suggested route in a graphical form, however, since public transport data for Australia is still undergoing refinement for inclusion in the Location Server, the public transport routing component was implemented independently. Nonetheless, the Whereis Location Server was used to generate pedestrian navigation instructions (and accompanying maps) for situations were tram stops were significantly distant from journey origin or destination positions, and for all the maps for the system. Since the Location Server was not performing the public transport routing request, it was not possible to show the tram route on the maps. As a work around, the start and endpoint of each journey segment were shown on the maps using iconic symbols.

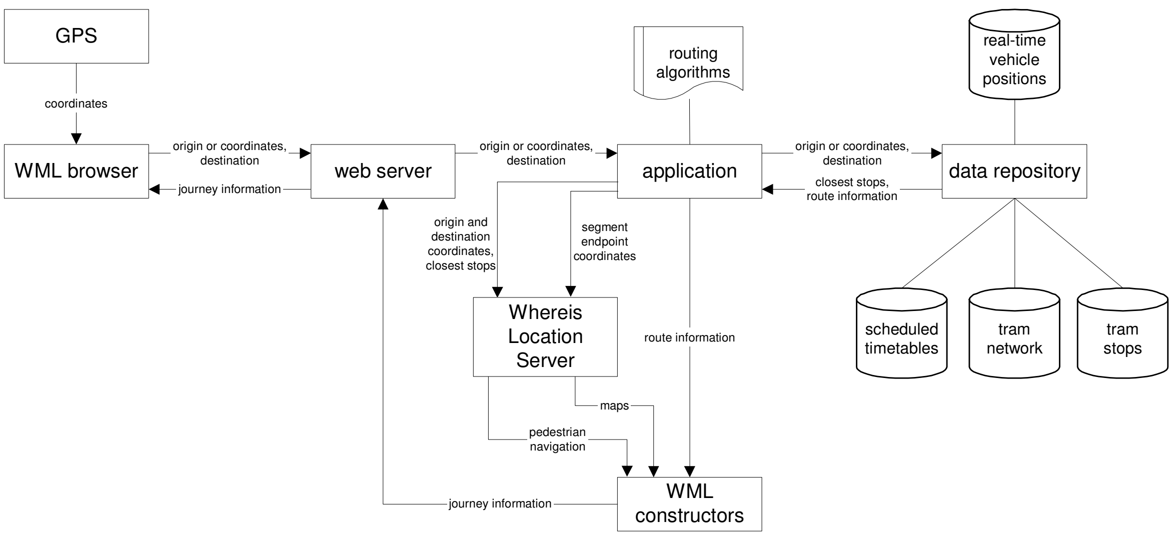


Figure 5-5 Prototype system structure

Data modelling and path finding or routing algorithms remain active research topics in the transportation field (refer to Peng & Huang 2000; Winter 2001). Typically focused on road network traversal, routing algorithms can not be directly related to transit situations due to their inability to deal with:

- time;
- the multiplicity between routes and streets and routes and stops – the 'common bus lines problem' (one street segment may serve many transit routes, one stop may serve many routes);
- the lack of symmetry between origin-destination and destination-origin pairs; and
- the dependency of vehicle transfers on the scheduling of other vehicles. (Peng & Huang 2000)

To overcome these problems, many specific transit network models have been developed (refer to Wong & Tong 1998; Tong & Richardson 1984; Spiess & Florian 1989; Costelloe, Mooney & Winstanley 2000). Categorised as either 'headway-based' (which assume that the traveller will take the first available vehicle along each street segment) or 'schedule-based' (which determines the time-dependent least cost path between origin-destination pairs), Peng and Huang (2000) identified that solutions in either category yield one and only one optimal solution for any origin-destination pair. Finding that this inflexibility in solutions is not ideal in the public transport area, they went on to develop their own hybrid algorithm, which uses both headway-based and schedule-based algorithms in a two stage process (Huang & Peng 2002). Primarily developed for bus networks, this algorithm was deemed equally applicable for a tram network.

5.4 Implementation

Achieving the desired user interface and functionality for the prototype application required the integration of several components. The structure of the final system is shown in Figure 5-5. Despite the incremental version approach, it was necessary to define the main structural components from the outset. The technology used to implement each component is shown in Figure 5-6.

The prototype was developed as a WAP application for the mobile Internet. WAP applications, designed for Internet enabled mobile devices, operate within a WAP browser and are implemented using the Wireless Markup Language (WML). An iPAQ PDA was selected as a representative user interface device for this application due to the benefits when compared with a WAP enabled mobile phone. The most prominent of these were the enhanced screen display and resolution, and the ability to connect a GPS receiver (allowing full control over the position determination of the device). Bluetooth connectivity between the iPAQ and a mobile phone was used to connect establish a GPRS data connection and provided data transfer rates equivalent to a standard WAP enabled phone.

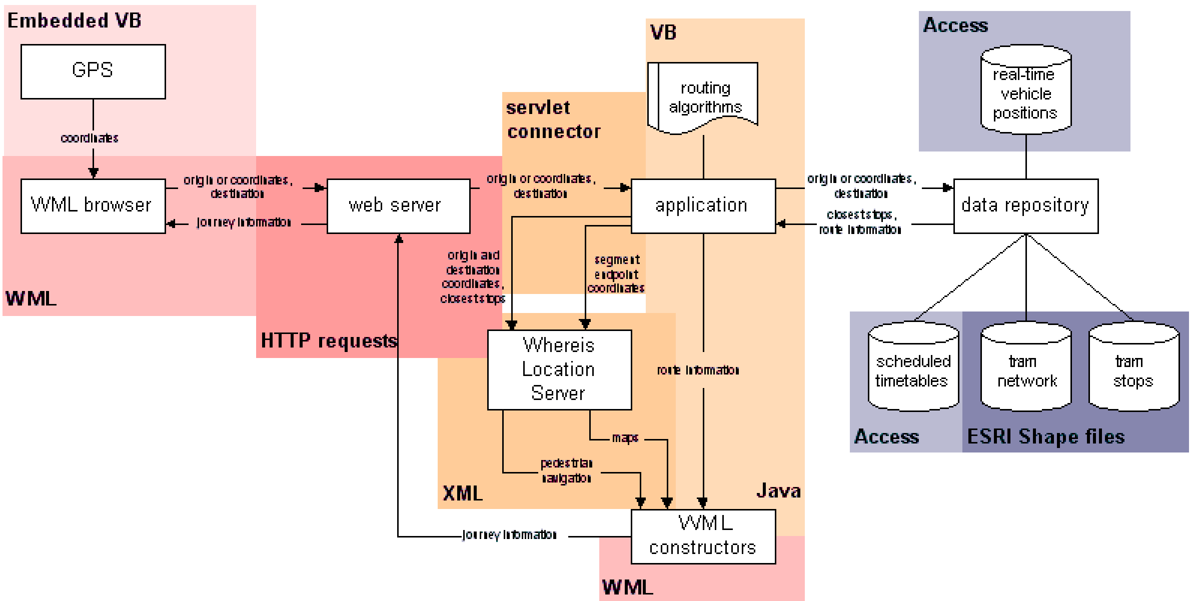


Figure 5-6 System components and underlying technology

The user interacts with the service via the WAP browser on their mobile device. Service requests are passed from the browser to the web server. The application listens for system related requests from the server and directs requests to the appropriate component as necessary. The application (including the routing algorithm) communicates with the data repository to determine an appropriate route between the specified origin and destination. The journey information is combined and constructed into a hierarchical series of WML documents that are presented by the web server to the user's browser.

In order to integrate the iPAQ with the GPS receiver, a small application that resided on the iPAQ was required. This application was developed by modifying Trupin's GPSBoy application – a publicly available application designed to collect data from a GPS satellite and chart the course of a user relative to the satellites (Trupin 2001). Although the GPS was required for only one of the three functions of the system, this application was used as the main interface for the system. This application was written in eMbedded Visual Basic®, a reduced version of Visual Basic® that is designed for Pocket PC (Microsoft® Windows® CE) operating systems.

As a result of the technologies used to implement the routing algorithms, and integrating with the responses from the Whereis Location Server, the WML pages for the application interface were implemented using three languages: Visual Basic, Java™ and WML. Visual Basic and Java were used to generate dynamic WML pages from XML (Extensible Markup Language) information returned from the Whereis Location Server and the routing algorithm, while the static pages of the interface were implemented directly using WML. Figure 5-7 depicts the interface flow for the prototype and indicates the technologies used to implement each screen. While probably not the most elegant programmatic solution, this configuration did allow all components to interact as necessary in order to provide routing solutions to users.

As discussed in Section 5.3, Peng and Huang's hybrid path finding algorithm (2000) was selected for this application. The algorithm was implemented in Visual Basic, capitalising on ESRI's MapObjects™ product to reference the spatial data required for the system and facilitating Internet delivery of the service.

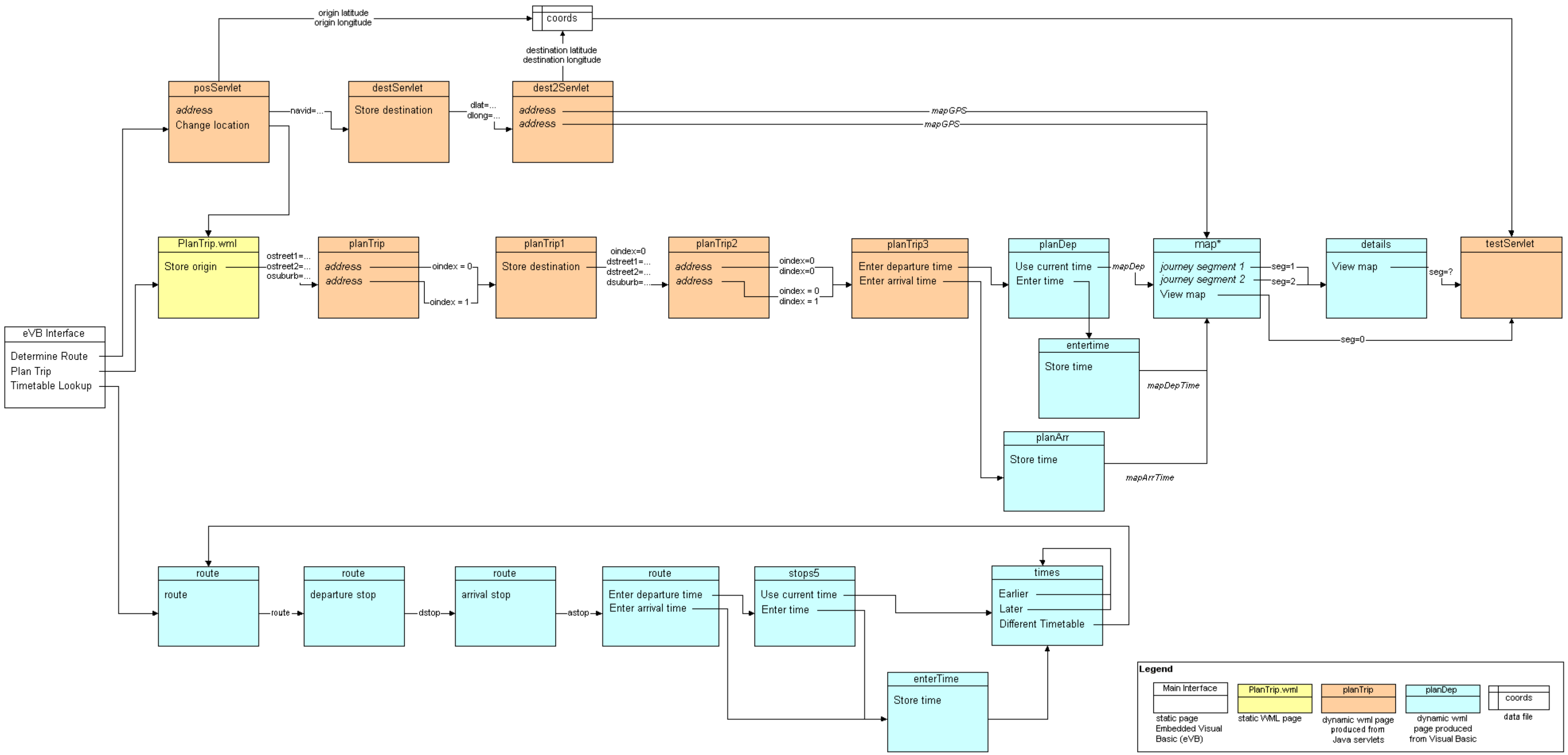


Figure 5-7 System interface flow

5.4.1 Database Schema

To implement Peng and Huang's path finding algorithm, one spatial and several a-spatial database tables were generated. Spatial tables were stored as ESRI shape files, and a-spatial tables in Microsoft Access. A description of each of the tables is provided in Table 5-3, with the relationship between each of the tables shown in Figure 5-8. The schema for the tables used is provided in Section 10.4 Appendix D. Original data supplied by the Department of Infrastructure included spatial databases for the:

- tram route network; and
- tram stops.

The tram route network data set did not provide any additional information to that contained in the stops data set, and hence the stops data set was predominantly used in the system. Timetable data for each route was obtained from the relevant transport operator's website (e.g. Yarra Trams: http://www.yarratrams.com.au; M Tram: http://www.movingmelbourne.com.au). The majority of the a-spatial tables required for the algorithm were generated by manipulating and categorising the spatial table for the tram stops (stops_gda) data set. To promote execution efficiency, the route finding algorithm searches only a subset of the entire tram network based on the time of travel for the proposed route. This requires some tables to be populated dynamically on each routing request to the system.

Table 5-3 Database tables used in prototype

Name	Description	
stops_gda.shp	Tram stops within the tram network. Each stop was classified into a ‘stopgroup’ and ‘transfernode’ for routing purposes. Tram stop numbering is not sequential along each route, and thus a field to record the sequential stop number for the route was required.	spatial
EventTable	Records events in the real world that could impact on the scheduled running of trams. Used to simulate real-time vehicle delays.	a-spatial
links_table	Records route possibilities between transfer nodes. Used to expedite the algorithm – don’t need to search every combination between two stops. Created by checking each transfer node for connecting nodes and recording the connecting routes and directions.	a-spatial
stops	Matches unique stop identifier with the stop number used in the real world (e.g. on tram stop signs). Created by extracting the ‘stops_id’ and ‘stid’ fields from stops_gda.shp. Rows with blank ‘stid’ were assigned a value of 0.	a-spatial
TransferNode	Matches transfer node with specific stop and route details. Created by selecting all records from stops_gda.shp with a ‘trnsfernode’ > 0, and then extracting ‘trnsfrnode’, ‘stops_id’, ‘stid’, ‘rte’ and ‘dir’ fields. Rows with blank ‘stid’ were assigned a value of 0.	a-spatial
Traversals	Dynamically generated table for each routing request containing possible network traversals based on tram timetable and transfer nodes. Rows are populated if a link existed between the two nodes and the scheduled time for the link was after the proposed travel time (in the case of a specified departure time).	a-spatial
routeXUschedule	Timetable information for tram route X in the up direction.	a-spatial
routeXDschedule	Timetable information for tram route X in the down direction.	a-spatial

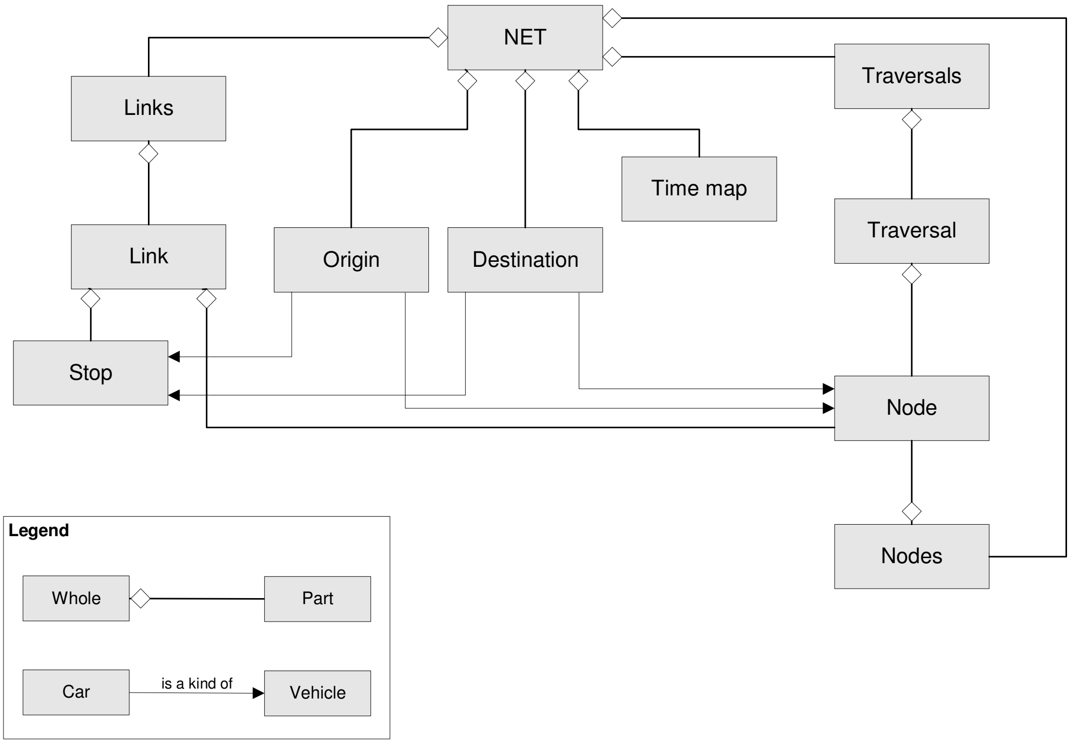


Figure 5-8 Object model (Huang & Peng 2002 p.9)

Given the reliance on both space and time, it is feasible to represent the objects of the transit network as a space-time objects as shown in Figure 5-8. Each object has a life span, during which time its spatial attributes may change. The *NET* object models the entire transport network and consists of an *Origin*, a *Destination* and a *Time map*. The *Origin* and *Destination* objects contain information about the origin and destination of the journey (represented as either street intersections or a coordinate position). The *Time map* is responsible for identifying active traversals between the origin and destination for the time of travel.

Traversals are unique sequences of *Nodes* from a starting point to an end point and are composed of segments or *Links* between two consecutive nodes.

Links contain the structural information of the network and represent segments of tram routes in the spatial database. The one *Link* can be used by many *Traversals*.

Stops are point events in the tram network and are uniquely defined by an identifier. Each stop has a location which can be described as a street intersection, or coordinate pair. A *Traversal* is related to a series of ordered stops, with each stop possibly serving multiple *Traversals*.

Stops at or close to a specific location, such as an intersection, can be classified as members of a specific stop group.

Transfer Nodes are point events within the tram network at which transfer between tram routes is possible. Start and end points of a *Traversal* are defined as transfer *Nodes*.

5.4.2 Demonstration Site

A web site providing a static demonstration of the prototype application is accessible at: http://www.geom.unimelb.edu.au/jcsmith, and on the accompanying CD (refer to Section 10.5, Appendix E). The demonstration is interactive and based on the flow of the tasks presented to evaluation participants (also included on the site). The demonstration was set up as a Web site (rather than a WAP site) due to constraints imposed on the application server which restricted its operation as a live site to the evaluation components of this research only. Additionally, this format allowed the entire application (including the GPS controls) to be demonstrated, and offered the ability to provide instructions and comments along with the application.

5.5 Testing

The testing regimen for the prototype was conducted in parallel with the development. Given the range of technologies used to implement the prototype a strategy of both black-box and white-box testing was adopted (Pressman 1997). White-box testing, which aims to test and exercise the independent paths, logical decisions, loops and data structures of the software, was carried out following the development of each component for each version. Black-box testing, focusing on the functional requirements of the software, was conducted individually for each component within each technology area, and then in conjunction with the other components to validate and verify the flow of the interface.

In addition to the white- and black-box testing employed, tests simulating use of the system were also performed for the first version of the prototype. This was undertaken in order to gain feedback on the general execution of the prototype, allowing for redesign of the algorithms if performance was poor. The following section describes the simulation testing and the associated results.

5.5.1 Performance Testing

Upon completion of the first version of the prototype, quantitative simulated use testing was undertaken. This involved recording use of the system by simulated users interested in determining a route between a series of representative tram stops. A live GPRS data connection was used for this testing, facilitating the capture of system execution times and transmitted data quantities. This information subsequently allowed representative usage costs to be calculated for the system.

Three sample routes were used in this testing process. The routes covered different journeys and as a result returned varying quantities of information. Test route 1 was a simple journey of six stops that could be completed using one tram. Test routes 2 and 3 both required interchanges from one tram route to another. The journey for route 2 required only one interchange (and passed through a series of six stops), while the route 3 journey required two interchanges and passed through ten stops. The testing process was repeated six times for each route to determine mean values for the response time per page and recorded server parameters. Even though this was a relatively small testing sample, the results obtained were relatively consistent. Usability testing theories developed by Nielsen suggest that typically only five users are required to identify the majority of usability problems (Nielsen & Landauer 1993). In this situation, the six repetitions indicate six independent users (each examining three test routes), and therefore exceeds Nielsen's scenario. Although this testing was examining only one aspect of usability (that of response time of the system) the number of test runs (representing users) utilised proved sufficient to examine system performance.

The three test routes demonstrated increasingly complex tram journeys, and hence the number of screens required to display the information to the user increased with each route (as is shown in Figure 5-9). Since route 1 was a simple journey that could be completed by boarding a single tram, only one result screen was presented. Routes 2 and 3 required the traveller to use two and three trams for their journey respectively, hence additional display screens were provided with information about the vehicle interchanges.

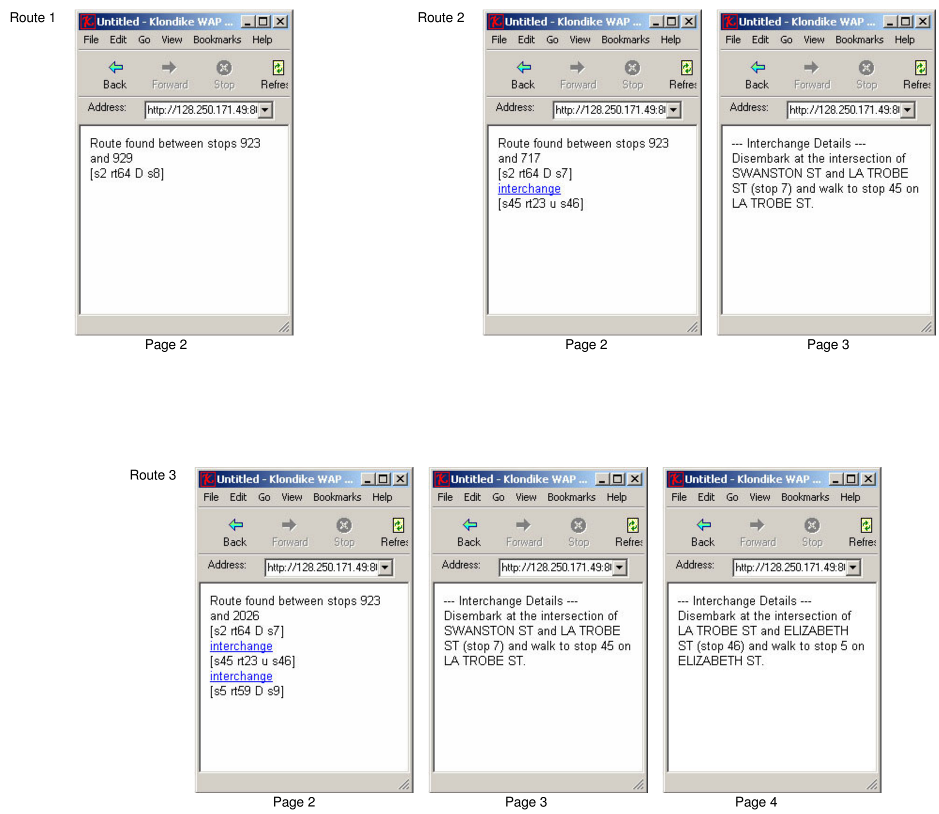


Figure 5-9 Examples of information presented to the user for each of the test routes

The following two tables show the times recorded to use the system and receive a response. Times were recorded for each of the six runs for each test route. Table 5-4 shows the breakdown of times for the transition between individual pages. Page 1 is the initial page that prompts the user for the tram stop numbers for their journey origin and destination; the other pages are numbered as per Figure 5-9.

Table 5-4 Application use – response time per page

	Page		Times (seconds)			
Route	From	To	mean	min	max	σ
1	1	2	14	11	19	03
	2	1	08	05	13	03
2	1	2	13	08	22	05
	2	3	10	07	26	07
	3	2	13	05	47	15
	2	1	07	03	13	03
3	1	2	14	11	17	03
	2	3	09	06	23	06
	3	2	11	06	33	10
	2	4	06	01	23	08
	4	2	09	07	12	02
	2	1	06	03	11	03
		Average	10			

Based on studies of attention thresholds and the fixed Internet, pages should load within ten seconds (Nielsen 2000). Although largely dependent on network speed, mobile users should also receive a response from the system within this ten second threshold. The simulated 'real use' testing of the application revealed that the response time for each page was 10 seconds on average (refer to Table 5-4), verifying that each WML page was appropriately sized and that the algorithms were executing at an appropriate speed.

Table 5-5 shows the results of the time taken and data quantities sent and received by a user obtaining and reading through the display screens as presented in Figure 5-9. The data quantities enabled the calculation of an approximate service cost to the user for obtaining the route information. This cost is only for the time and data transferred by the service, and does not include any additional charges associated with the privilege of accessing the service or the associated data as would be likely in a commercial application.

Table 5-5 Application use – client perspective

	User Time (seconds)		Data (bytes)		
Route	mean	σ	mean	σ	Cost
1	20	07	3838	437	$ 0.08
2	47	30	6590	545	$ 0.13
3	57	32	9166	712	$ 0.18

Note: Cost calculation based on a charge of A$ 0.02 per kilobyte

As discussed previously, issues from an end user's perspective are related to interaction with the service in competition with other tasks. Users do not want their service interaction to be time consuming nor impeded by other concurrent users. The testing revealed that even for a relatively complex route, relevant information could be accessed and read in less than one minute, and for what could be regarded as a minimal cost. Although the user time experiments were subjective, based on approximations of user input and reading speeds, they did suggest that the volume of data presented was appropriate.

LBS are rarely going to be accessed by a single user, therefore multiple users were simulated accessing the system concurrently. Access to the specific URLs that activate the route generation by the application were tested for speed and bandwidth use. Again this was conducted in a series of runs to obtain average representative values. The mean values (for five simulations of five users) of attributes that would impact on an end user's experience of the system were recorded and are shown in Table 5-6.

Table 5-6 Application use – server perspective
(mean values shown for simulated access by five simultaneous users)

Average User Wait Time of all Users (ms)	1428.6
Average User Bandwidth (kB/s)	0.5176
Hit Count	5
Hits per second	1.9956
Average User Wait Time of all URLs (ms)	1428.6
Total bytes	2602.8

Even with five simultaneous users performing route requests, the average wait time for all users was just over one second – this is considered only a minimal delay, and one that would be only just noticeable by a user. This again verified that the algorithm implementation was adequate.

5.6 Assumptions and Limitations

Whilst designed for the lowest type of handheld device, implementation decisions meant that the final prototype could not in fact be viewed on this type of device, as detailed below.

5.6.1 GPS Integration

The need to control the positioning component of the service resulted in the use of the iPAQ with a GPS receiver. The software required to control the GPS receiver and link it to other parts of the system had to be manually installed on the iPAQ device. This software in its current form would not run on currently available mobile phones.

5.6.2 Map Image Format

The Whereis Location Server was capable of returning WBMP (Wireless Bitmap) images suitable for inclusion in WML pages. However, this image format was not directly supported by the Server and no optimisation techniques were employed on the translation between the original vector data sets and the output map image. As shown in Figure 5-10, these types of images would provide more confusion than assistance to users. Thus GIF (Graphics Interchange Format) images, the native format of the Whereis Location Server, were used (refer to Figure 5-11). GIF is not a format that is usually supported by WAP, however some WAP browsers are capable of displaying images of this format. A GIF supporting WAP browser was installed on the iPAQ device used for testing and allowed clearer, colour images to be used by the system.

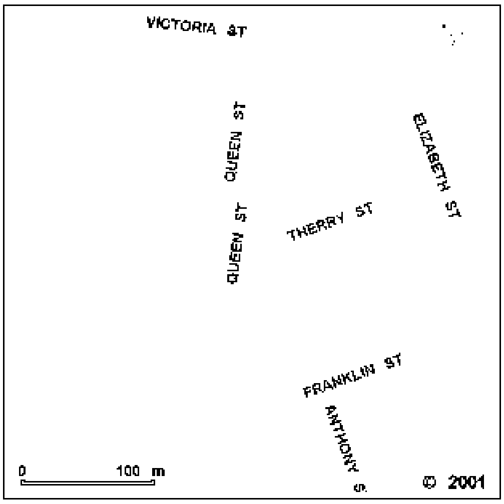


Figure 5-10 WBMP image from Whereis Location Server

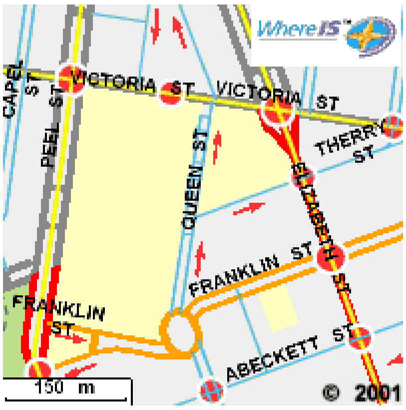


Figure 5-11 GIF image from Whereis Location Server

Given the API interface to the Whereis Location Server it was possible to request both WBMP and GIF images for each routing request. The application made use of only the GIF images, but it could equally use the WBMP images if they had been of adequate quality. The flexibility of the API offers the potential for the application to be device dependent; the application could detect the type of device accessing the service and provide WBMP images to mobile phone users and GIF images to PDA users.

5.6.3 Data Entry

Given the prototype nature of the system and the fact that most participants would be guided through their interaction with the system, only a few input detection error solutions were employed. Simple treatment such as ensuring that data entry fields were not case sensitive and could handle spaces in street names (e.g. Little Bourke) were employed, but more sophisticated error checking (including phonetic matching algorithms for suburb or street names) that would be expected of a commercial application was not employed.

The option of presenting a clickable, interactive map for the selection of origin and destination, was beyond the technological capabilities of the Whereis Location Server at the time of development. Since this time Webraska (responsible for the API that interacts with the Whereis Location Server) has been working on this form of interaction.

5.6.4 Data Used

While the entire metropolitan tram network and stops were obtained from the Department of Infrastructure, timetable data was more difficult to source. Scheduled timetable information was available for the tram routes via the relevant operator's websites, and thus this information was downloaded, appropriately formatted and used to populate the necessary database tables. This was performed for only a small sample of the tram routes in the metropolitan area due to the labour required in inputting this data into the system. The sample tram routes selected for the prototype covered the most popular tram routes within the inner city area and intersected several other routes, attempting to incorporate the spatial complexity of the entire tram network.

5.6.5 Route Display

Due to the two independent systems responsible for processing routing requests (prototype system) and map display requests (Whereis Location Server) it was not possible at the time of development to represent the tram journey graphically on the requested maps. Instead only journey end points could be identified by the use of icons on the map.

Webraska have since developed the API to allow routes, consisting of a series of coordinates, to be superimposed on a map. Previously graphical route display was only possible for routes determined by calls to the API system itself; this was what was used for the walking directions and routes to and from tram stops when required.

5.7 Conclusions

This chapter has documented the development process of the prototype in terms of the development phases: requirement specification, analysis and design, implementation and testing.

Whilst originally intended to be a generic WAP application, implementation decisions led to the application being specifically suited to WAP browsers that support GIF images.

The following chapter describes the outcomes of the evaluations conducted using the system.

Chapter 6 Evaluation Outcomes

This chapter presents the results from the two prototype evaluations – the walkthrough evaluation and the usability evaluation. Analysis of the questionnaire responses from the evaluations has drawn out the respective SDI requirements regarded as important for wireless information access and dissemination.

6.1 Introduction

In accordance with the method described in Chapter 4, two evaluations involving the prototype LBS application (described in Chapter 5) were carried out to assist with determining the SDI requirements necessary for spatial wireless applications. Initially the two evaluations were analysed independently, and the participant categorisation (SDI People Category for the walkthrough evaluation and laboratory or field context for the usability evaluation) was disregarded.

Comparisons between the two evaluations were made and trends between various participant categories explored in subsequent analysis, the results of which are presented in the next chapter.

6.2 Walkthrough Evaluation

In total twenty four subjects participated in the walkthrough evaluation, and encompassed a range of private and public sector organisations and service end users. The first section of the questionnaire was designed to gather personal profile information from the participants. A roughly equal gender balance was observed with 14 males and 10 females participating in the evaluation. The majority of participants fell within the 26 – 35 age bracket as is shown in Figure 6-1.

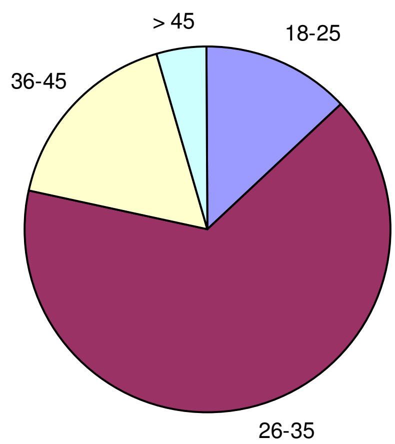


Figure 6-1 Age distribution of walkthrough evaluation participants

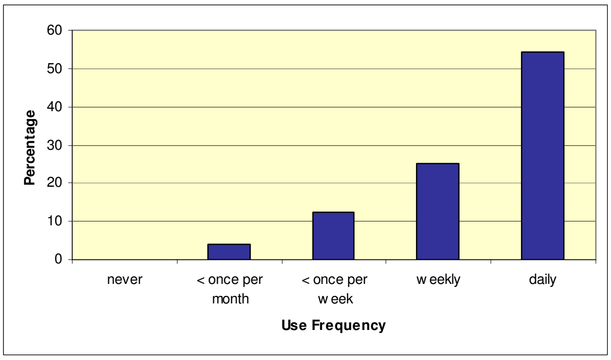


Figure 6-2 Recreational computer use (walkthrough evaluation)

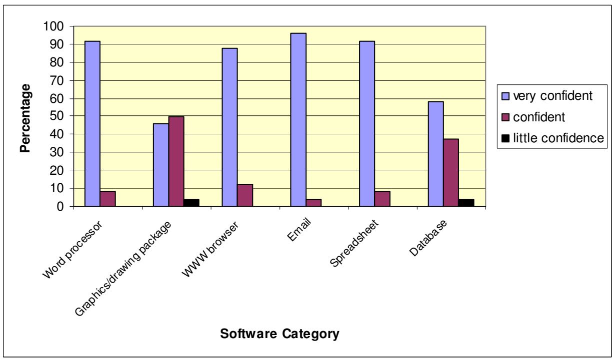


Figure 6-3 Software confidence (walkthrough evaluation)

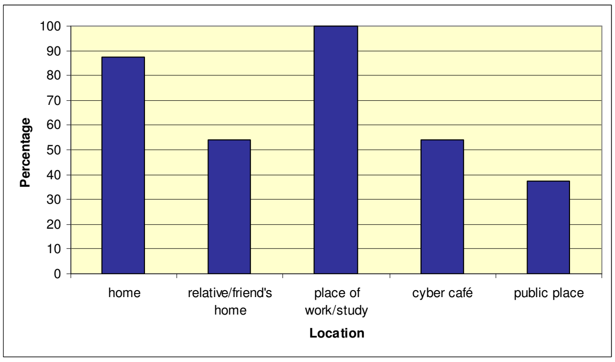


Figure 6-4 Internet use – location (walkthrough evaluation)

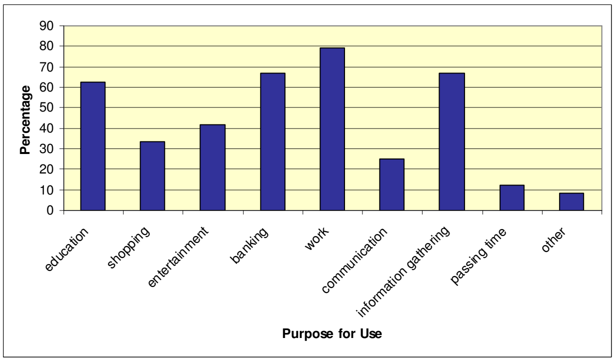


Figure 6-5 Internet use – purpose (walkthrough evaluation)

The second section of the questionnaire was designed to assess the participant's experience with computing and mobile device technology.

All participants used computers daily for work purposes, and approximately half (54%) used computers just as frequently for recreational purposes (refer to Figure 6-2). Overall, participants demonstrated a strong level of computer literacy and were highly confident in dealing with a range of software packages, with only the more specialised software applications (graphics/drawing packages and databases) proving more challenging to participants (refer to Figure 6-3).

As expected amongst this group of participants, the Internet played a big role in their computing time with all but one participant using the Internet on a daily basis. The location of Internet use was distributed across both private and public locations (as shown in Figure 6-4), and was most commonly used for work/business, information gathering for personal needs and banking (refer to Figure 6-5).

Eighty eight percent of the participants owned or used a mobile phone and as shown in Figure 6-6, mainly utilised the voice and SMS capabilities of the device. Twenty percent of participants owned or used another mobile device in addition to their phone with digital organisers, electronic diary, PDAs, and communicator devices representing these additional devices. Twenty five percent of the participants' mobile phones were WAP or Internet enabled however this functionality was rarely used (refer to Figure 6-7). The infrequency of use did not seem to result from a lack of confidence on behalf of the participant's ability to use these capabilities, with most feeling confident in their ability to use the Internet on their mobile phone.

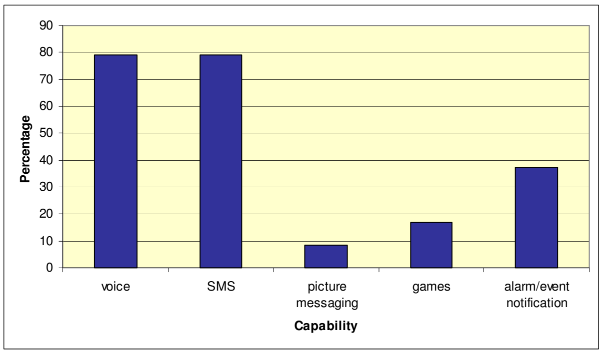


Figure 6-6 Mobile phone capability usage (walkthrough evaluation)

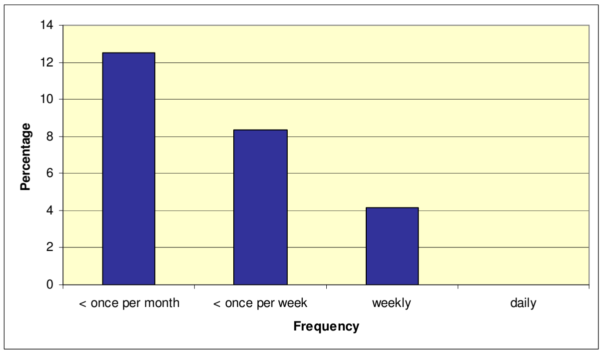


Figure 6-7 Mobile Internet use (walkthrough evaluation)

The third section of the questionnaire aimed to determine the participant's confidence in their spatial ability. Seventy five percent of the participants had completed a Geomatics related course at a tertiary level and typically felt very confident in their ability to perform a range of basic navigation and map reading skills (refer to Figure 6-8). Whilst this analysis provides no indication of accuracy of the participant's statements, it is interesting to observe the confidence trend. The spatial task deemed most challenging by the participants was that of providing distances and directions in relation to a route. This matched a spread of confidence levels in the task of identifying north orientation.

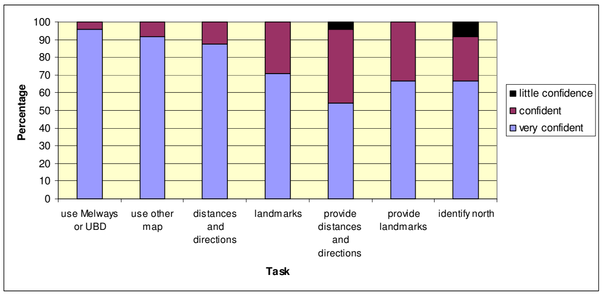


Figure 6-8 Spatial task confidence (walkthrough evaluation)

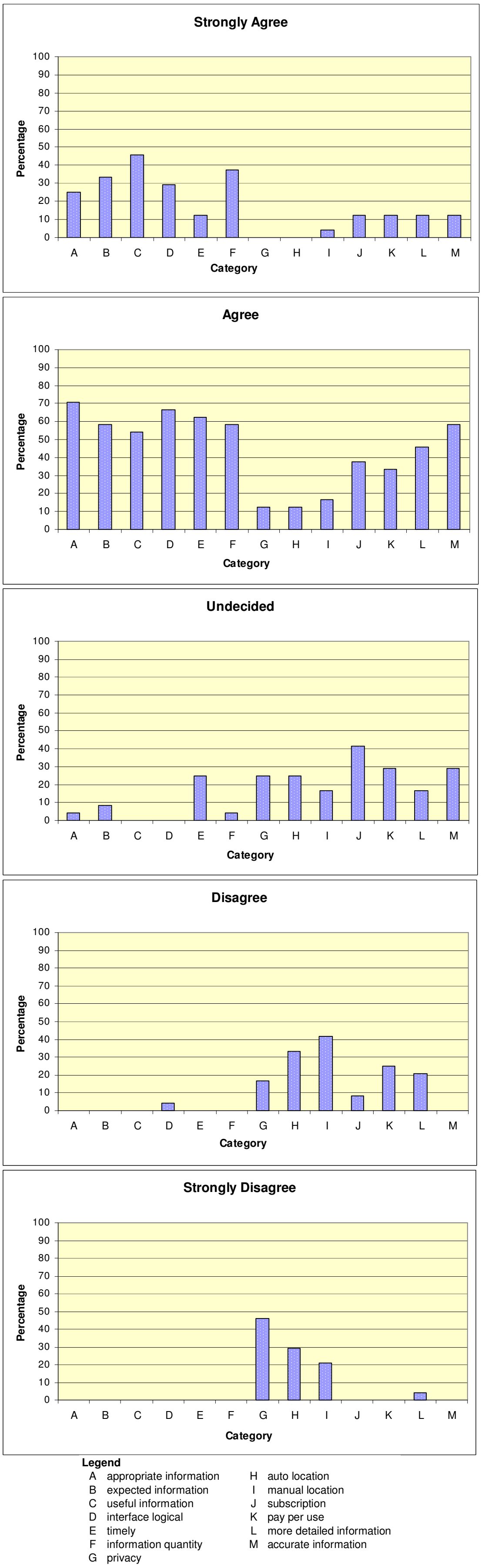


Figure 6-9 Application satisfaction (walkthrough evaluation)

The fourth section of the questionnaire elicited information about the suitability of the prototype for the purposes of assisting with tram travel, and the underlying SDI issues.

Participants were asked to respond with their level of agreement to statements about the prototype application using a Likert Scale. Participants expressed strong agreement in the statement that the application provided useful information that could be utilised to travel from an origin to a destination and the quantity of information presented on each screen (refer to Figure 6-9 – Strongly Agree). The majority of responses were in agreement with the positive statements and participants agreed that the application provided appropriate information for the task, offered a logical interface and responded in a timely manner (refer to Figure 6-9 – Agree). Indecision was concentrated around the payment method for this type of service (refer to Figure 6-9 – Undecided). Somewhat unexpectedly, participants did not have concerns about the location capabilities of the application (Figure 6-9 – Disagree) and were not concerned by the privacy implications of the application (refer to Figure 6-9 – Strongly Disagree).

Analysing the rankings provided for the proposed SDI requirements revealed some interesting trends. Although the responses were often well distributed across the twenty three requirements, a few common issues emerged. Initially responses were categorised based on the assigned rank.

Ranked most frequently as the most important issue was quality in relation to the data within the system (refer to Figure 6-10 – Rank 1). The issue regarded next important (ranked second and third, refer to Figure 6-10 – Rank 2 and Rank 3) by participants was that of response time indicating the value that users place on timely systems. This was closely followed by data standards and quality (ranked second) and privacy and scale (ranked third). Leading the fourth most important ranking was data maintenance (refer to Figure 6-10 – Rank 4). Equally ranked as the fifth most important issue were interoperability, maintenance and data volume (refer to Figure 6-10 – Rank 5).

These issues seem to strongly reflect responses that would be expected from data providers or application integrators, and analysing the rankings according to these groups revealed some slightly different perspectives (this analysis is described in Section 7.3).

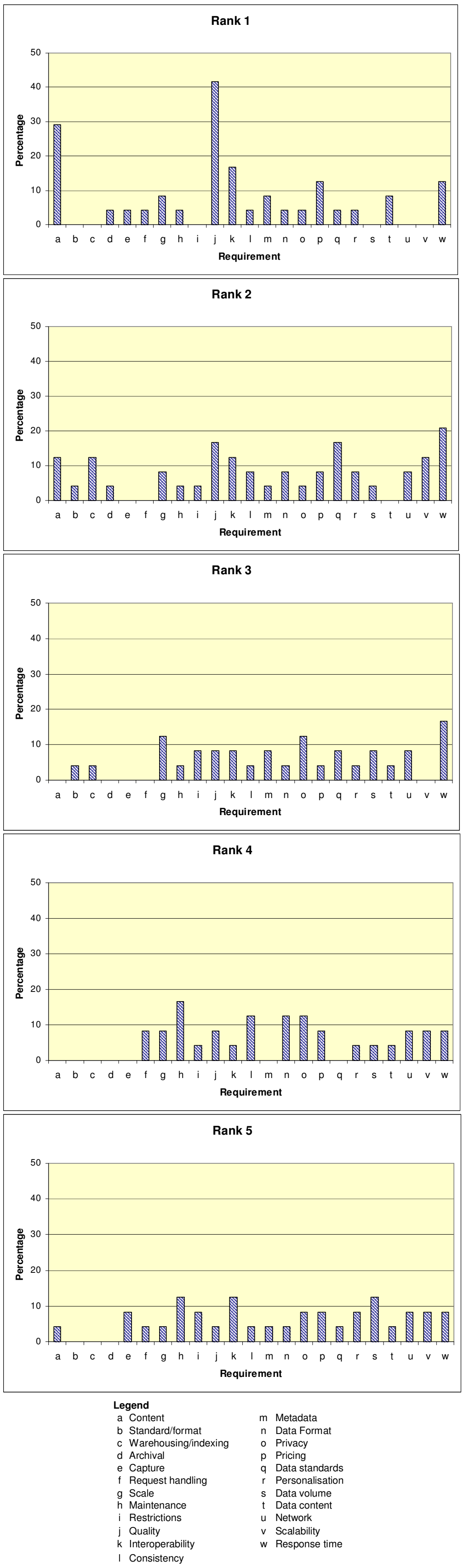


Figure 6-10 SDI requirement ranking (walkthrough evaluation)

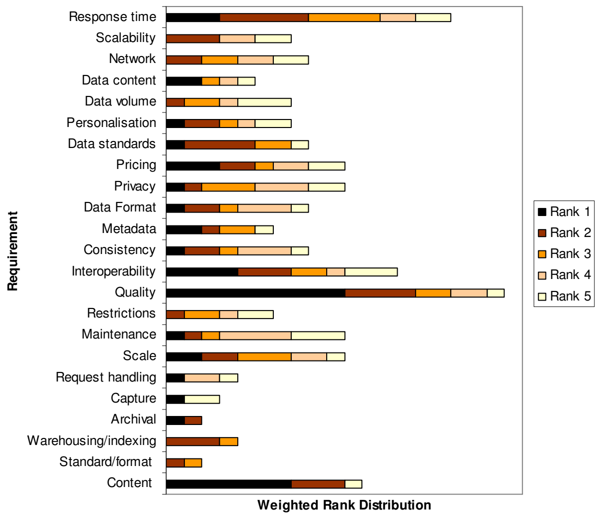


Figure 6-11 SDI rank distribution (walkthrough evaluation)

The distribution of ranks applied to each requirement was also of interest (refer to Figure 6-11). Requirements that were most highly ranked were quality, response time, content and interoperability. These issues all relate to the end user experience of an LBS.

While none of the requirements were deemed as irrelevant, some participants suggested additional requirements for SDI that would be beneficial for a public transport LBS, including:

- Relationships with public transport operators;
- Interface/interaction with real-time position of vehicles;
- Interface/interaction with other real-time data (e.g. traffic, timetable changes/delays);
- Service access reliability – linked to communications network and service providers; and
- Relationships with and between service providers.

Some participants also provided a 'wish list' for the application:

- an improved user interface, developed through consultation with end users and industry, that is easy to use and provides proper error messages;
- cater for multimodal journeys (tram, train and bus); and
- user education when signing up for the service to understand its limitations.

The overall requirement rank from this evaluation is shown below in Table 6-1. This ranking has been determined by applying a weight for each rank (e.g. rank 1 assigned a weight of 10, rank 5 assigned a weight of 2). The total of these weighted rank values were then summed for each requirement – producing a weighted requirement value. These requirement values were then sorted to produce the ranked list of requirements shown below. The top five requirements are spread across the SDI categories of Data, Access and Standards, highlighting the integrated nature of the components.

Table 6-1 SDI requirement ranking (walkthrough evaluation)

Requirement	Rank
Quality	1
Response time	2
Content	3
Interoperability	4
Scale	5
Pricing	6
Data standards	7
Privacy	8
Maintenance	9
Consistency	10
Data Format	11
Metadata	12
Personalisation	13
Network	14
Scalability	15
Data content	16
Warehousing/indexing	17
Data volume	18
Restrictions	19
Request handling	20
Archival	21
Standard/format	22
Capture	23

6.3 Usability Evaluation

Ten subjects participated in the usability evaluation, five undertaking the tasks in the field and five in the laboratory. As in the walkthrough evaluation, a gender balance was maintained across the sample. The age distribution of participants differed from the previous evaluation however with the majority falling within the 18 – 25 age bracket as is shown in Figure 6-12.

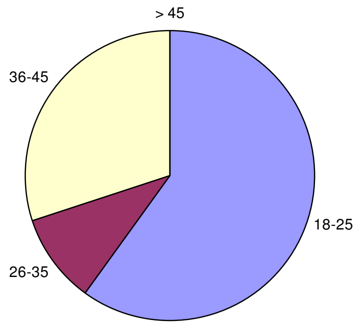


Figure 6-12 Age distribution of usability evaluation participants

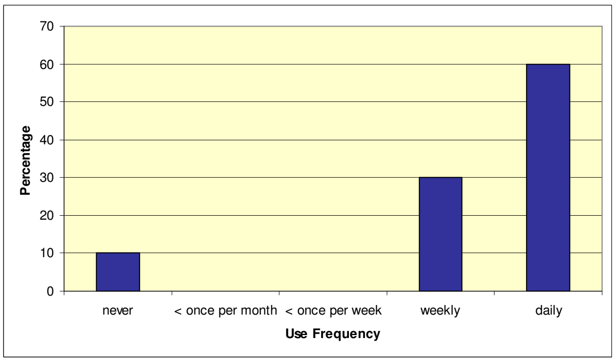


Figure 6-13 Recreational computer use (usability evaluation)

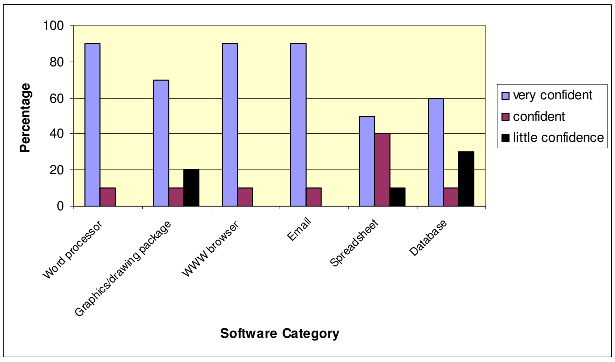


Figure 6-14 Software confidence (usability evaluation)

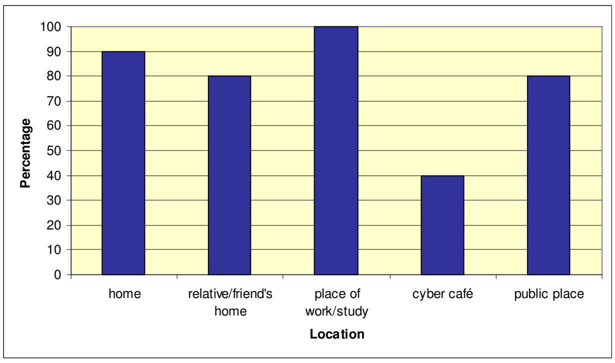


Figure 6-15 Internet use – location (usability evaluation)

As was observed in the walkthrough evaluation, all participants in this evaluation were highly computer literate and used computers daily for work purposes; 60% of participants indicated the use of computers daily for recreational purposes (refer to Figure 6-13). Again, a similar trend was observed in the confidence levels related to different categories of software with spreadsheets and graphic packages proving challenging, and databases indicated as the most challenging by these participants (refer to Figure 6-14).

The Internet was again a frequently used resource with all participants indicating daily use. The distribution for the location of use followed a similar trend to the responses obtained from the walkthrough evaluation, with the place of work/study and home being the locations most commonly used to access the Internet (refer to Figure 6-15). A similar trend was also observed in the purpose of Internet use with the top three ranked uses being: work/business related, information gathering and education.

All participants had a mobile phone which they used mainly for SMS and voice communication (as shown in Figure 6-16). Forty percent of participants used or owned a PDA or digital organiser. Only 20% of the participants' mobile phones were WAP enabled and these participants used this functionality relatively infrequently (though their confidence with its use remained high).

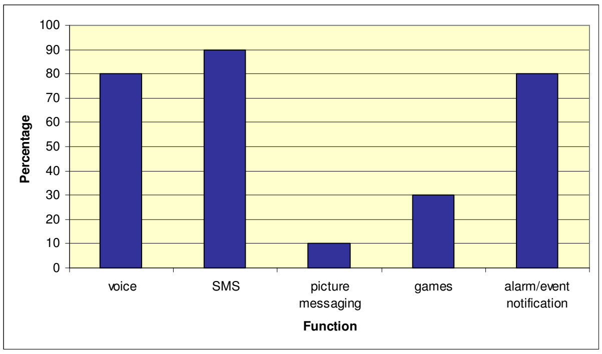


Figure 6-16 Mobile phone capability usage (usability evaluation)

None of the participants of this evaluation had undertaken any Geomatics related courses beyond high school, and expressed a low degree of confidence in most of the spatial tasks (refer to Figure 6-17). The one task that participants expressed significant confidence in was that of using Melways or UBD maps (these map products occupy the stronghold of the market share of mapping products in Melbourne). The task deemed most challenging by this group was that of identifying north orientation.

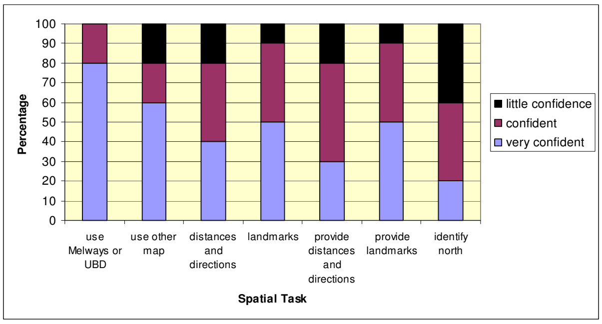


Figure 6-17 Spatial task confidence (usability evaluation)

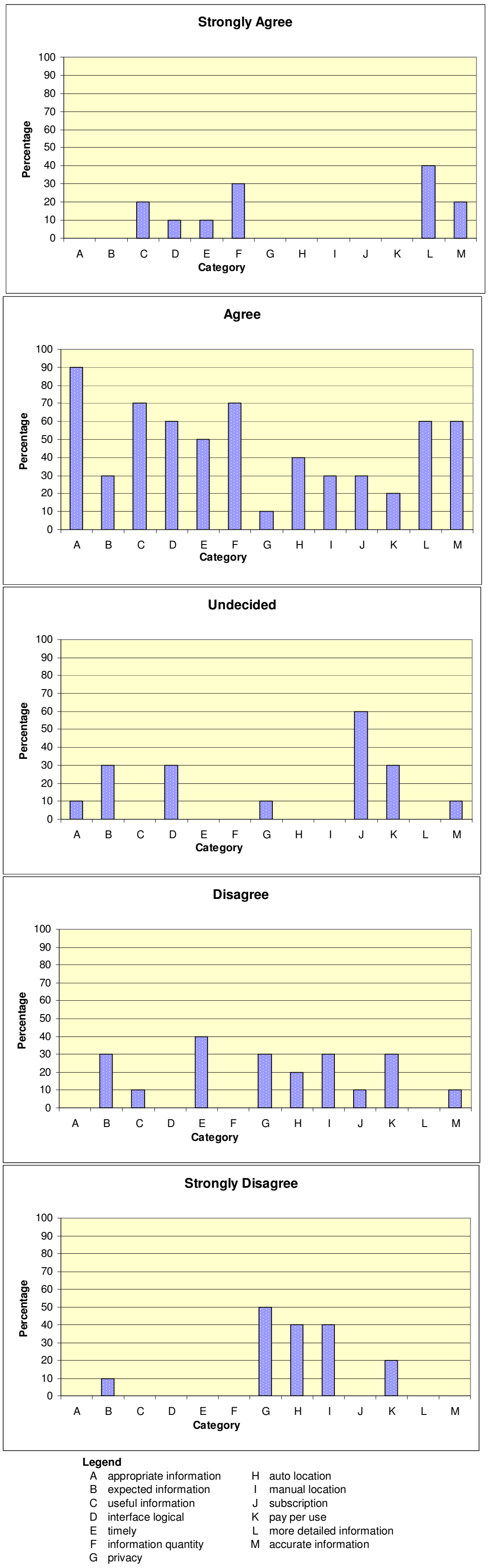


Figure 6-18 Application satisfaction (usability evaluation)

While the responses of this group were similar to those received from the participants in the walkthrough evaluation (typically agreeing with the statements provided), here they reflected the usability and applicability of the system in the real world (i.e. in context).

Forty percent of participants expressed strong agreement with the statement that the application should provide more detailed information (refer to Figure 6-18 – Strongly Agree). Responses were again focussed in the 'agree' level of the scale, with ninety percent of participants agreeing that the information provided by the application was appropriate for the purposes of journey planning and execution (refer to Figure 6-18 – Agree). Participants were typically undecided about the suitability of this type of application to a subscription payment method, and felt that the system operation was slow (refer to Figure 6-18 – Undecided). Participants were not concerned about the location capabilities of the application, nor were they worried by the privacy implications (refer to Figure 6-18 – Disagree and Strongly Disagree).

Similarly to the analysis of the previous evaluation, responses to the proposed SDI requirements were categorised based on the rank assigned by participants.

Ranked most often as the most important issue was data content (refer to Figure 6-19 – Rank 1). Of secondary importance was the scale of the data (refer to Figure 6-19 – Rank 2). Ranked third most important was the issue of personalisation or customising the application for frequent use or user behaviour (refer to Figure 6-19 – Rank 3). This was ranked equally with content, but content had already been classified as the most prominent issue and was therefore disregarded for this ranking. Equally ranked fourth were issues of: consistency, metadata, data content (in terms of the form, entities and entity relationships of the information presented to the user) and response time (refer to Figure 6-19 – Rank 4). Ranked as the fifth most important issue was scalability (refer to Figure 6-19 – Rank 5).

As somewhat expected, given the nature of this evaluation, these rankings strongly reflect the views of end users.

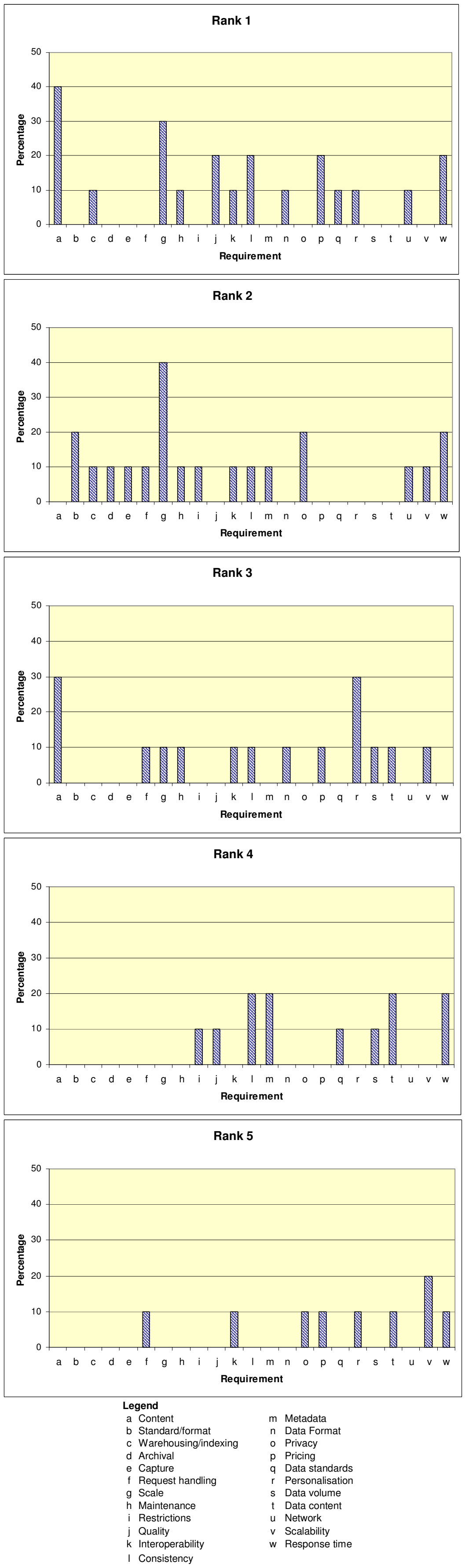


Figure 6-19 SDI requirement ranking (usability evaluation)

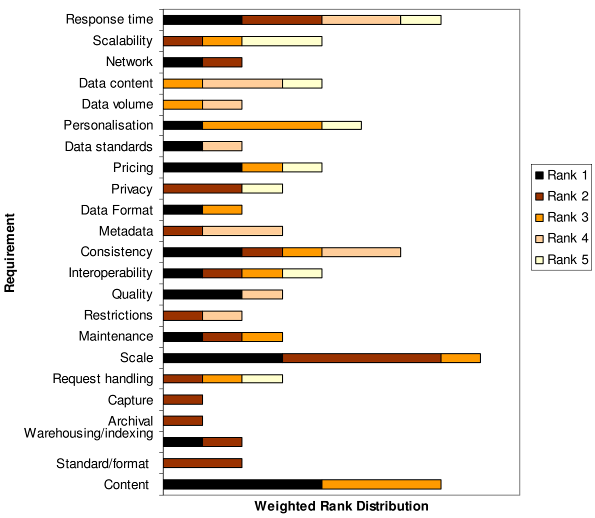


Figure 6-20 SDI rank distribution (usability evaluation)

Most highly ranked overall was the scale requirement relating to the size and level of detail of map information displayed (refer to Figure 6-20). Accurate and appropriate maps were highly sought after by this group of participants, due to the fact that half of them had to physically complete the tasks in the real world. The maps proved troublesome in this environment, mainly due to a lack of street labelling (refer to (Graham et al. 2003) for more details about the usability problems encountered with the system).

An additional improvement made by one participant suggested that the application give information to the user as soon as it could be determined. The information delivery hierarchy, and the flow between screens did not contribute to the usability of the system.

The overall requirement rank from this evaluation is shown below in Table 6-2. This ranking has been determined using the same method as for the overall rankings from the walkthrough evaluation. From this evaluation the top five requirements are spread across the Data, Access, Standards and Policy SDI Categories, again highlighting the integrated nature of the components. As expected, the overall rankings reflect the participants’ consideration of the application (and LBS) as a real application intended for use by the general public, and hence the highest ranked items relate to the usability and customisation of the system.

Table 6-2 SDI requirement ranking (usability evaluation)

Requirement	Rank
Scale	1
Content	2
Response time	3
Consistency	4
Personalisation	5
Pricing	6
Interoperability	7
Maintenance	8
Quality	9
Warehousing/indexing	10
Privacy	11
Network	12
Scalability	13
Standard/format	14
Request handling	15
Metadata	16
Data Format	17
Data content	18
Data standards	19
Restrictions	20
Data volume	21
Archival	22
Capture	23

6.4 Conclusions

This chapter has presented the results of the preliminary analysis from the two evaluations conducted in order to determine the requirements of SDI for wireless, spatial applications.

The two evaluations revealed a slightly different emphasis on the importance of SDI requirements. Walkthrough evaluation participants regarded data quality as the most important, while the size and level of detail of map information was regarded of paramount importance by the usability evaluation participants. These two issues are both derived from the Data SDI category however their emphasis, as well as the ranking of the other requirements, strongly reflects the type of evaluation conducted. The requirement ranking from the walkthrough evaluation indicates an appreciation of the entire SDI environment, while the usability evaluation ranking demonstrates a practical, application usability approach.

In addition to the differences attributed to the evaluations themselves, differences in rankings could also be linked to the characteristics of the participants. To explore these issues in greater depth, the following chapter compares the results from the two evaluations, examines the SDI requirement differences based on a variety of participant categorisations and synthesises the evaluation results in terms of the SDI people categories.

Chapter 7 Discussion/Analysis

This chapter begins by comparing the two evaluation methods and the different results obtained, particularly for the use of the application. Further investigation of the rankings associated with each of the issues identified for the SDI components is undertaken by examining different groupings of evaluation participants. The issues are extracted for each of the SDI people categories and an expanded SDI model is developed for each category.

The limitations of the expanded SDI model are discussed and justification for accepting the research hypothesis is provided.

7.1 Introduction

The two evaluation methods adopted for this research produced a number of interesting commonalities and differences. Overall, the responses to questions relating to the use of the application were as expected, however the SDI rankings that emerged from each evaluation group was unexpected.

In order to investigate the areas of commonality, and help to identify an explanation for the differences, the evaluation methods and results were initially compared. A categorisation of participants was also undertaken to identify trends across particular groupings. This approach, along with an overall discussion regarding the impact on the additional aspects for each of the SDI components, is presented in the following sections.

7.2 Evaluation Comparison

The two different evaluations produced subtly different responses and provided a useful comparison reflecting on the issues associated with mobility. The participant profile and tasks undertaken in the different evaluations cannot be disregarded in this comparison, and facets of the evaluation that could have directly influenced particular responses have been indicated where appropriate.

The participant profile for the walkthrough evaluation encompassed a range of professionals through to students, many of whom had a strong background of spatial training. While all participants gave their impressions of the application from the perspective of an end user, for this reason their opinion of the system was potentially biased. Participants in the usability evaluation however had no specific spatial training. As a result, this group of participants could be regarded as being more representative of the general public. Their predominant background in Information Science assisted in the articulation of general usability problems with the application.

The walkthrough evaluation (in which users were guided through routing requests) directed focus away from the usability of the application while this was the main focus of the usability evaluation. The two evaluation approaches resulted in differing responses to both the SDI requirements and feedback regarding the application, despite all participants displaying a high degree of computer literacy and relatively high confidence in completing spatial tasks.

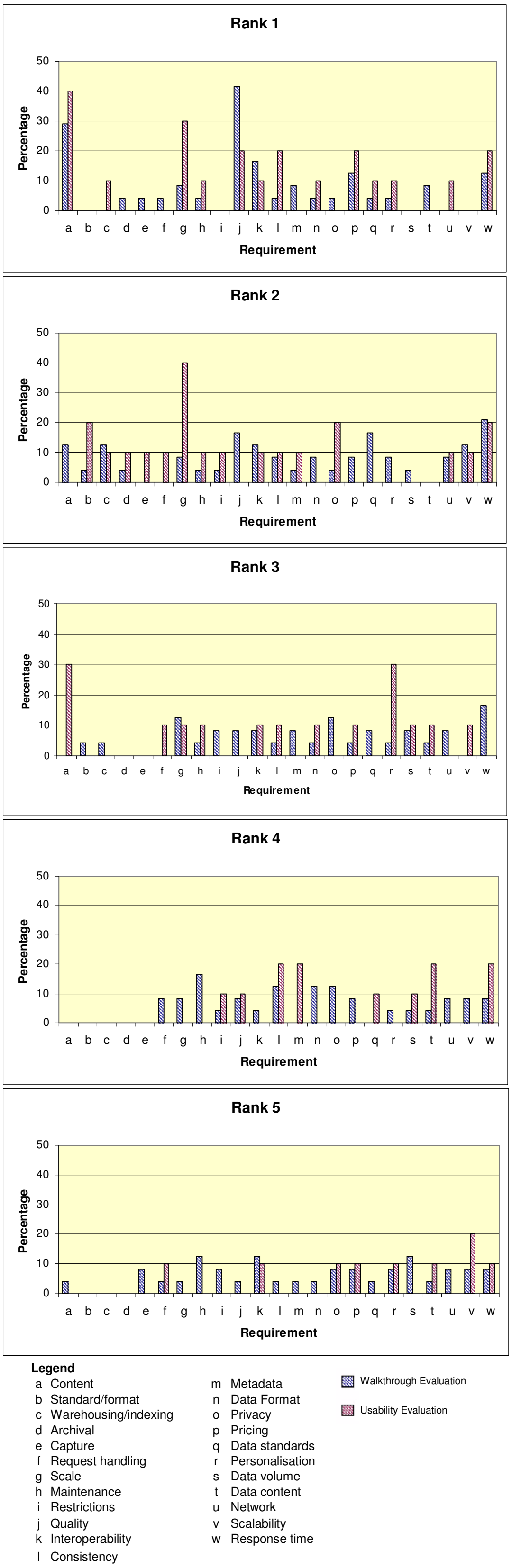


Figure 7-1 SDI ranking - evaluation comparison

By comparing the SDI ranking responses from the two evaluations (refer to Figure 7-1) it was evident that the participants who used the application in the real world to perform real tasks identified issues related to mobility and the use of spatial information in varying environmental contexts, while those participating in the walkthrough evaluation provided a more holistic view (likely biased by their involvement in the spatial information industry).

The distinction between ‘quality’ and ‘content’ made by walkthrough and usability participants respectively (refer to Figure 7-1 – Rank 1) highlights the differing emphases. To end users, the entities and entity interactions within a data set are critically important. While strongly related to content, the ‘quality’ issue identified by walkthrough participants encompasses content at a more theoretical level relating characteristics (such as lineage, positional accuracy, attribute accuracy, logical consistency, completeness and temporal accuracy) to a product designed for stated and implied needs.

Considering the evaluation of the application itself, the two evaluation methods revealed a number of strong correlations, but also some notable differences. Common trends occurred for responses to the appropriateness of information (with the majority of participants of both evaluations agreeing that the information provided was appropriate), the usefulness of the information presented (the majority of participants of both evaluations agreeing – only one participant from the usability evaluation disagreed about the usefulness of the information), the logic flow of the interface (the majority of participants of both evaluations agreeing – only one participant from the walkthrough evaluation disagreed), the quality of information provided (majority agreement), the concern about privacy infringements by the application (typically strong disagreement was expressed, although a few participants responded more weakly), the willingness to subscribe to this sort of service (approximately normal distribution around the central level of 'unsure'), the willingness to pay for this service on a usage basis (almost even distribution across all agreement levels but overlapping between evaluations - walkthrough ranging from 'disagree' to 'strongly agree', usability ranging from 'strongly disagree' to 'agree'), and the accuracy of information provided by the application (majority agreement across evaluations).

There were a number of areas where trends between the evaluation groups did not concur. The information expectations were met for the walkthrough evaluation participants, however usability participants expressed general dissatisfaction with the information presented by the system compared to their expectations (refer to Figure 7-2). This could be due to the fact that usability participants were not briefed specifically about the map limitations (in particular regarding the lack of tram route marking on the maps) whereas this fact was explained to the walkthrough evaluation participants.

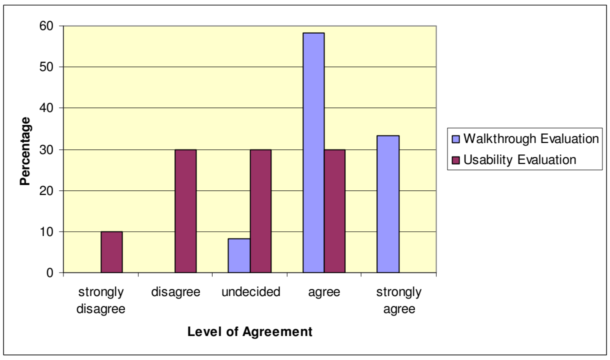


Figure 7-2 System information expectations (by evaluation)

Response to the measure of satisfaction with the time taken for the system to deliver information produced differing results; walkthrough participants were satisfied with information delivery speeds while usability participants were less satisfied (refer to Figure 7-3). This highlights the importance of timeliness in applications used by people in the real world. This variable could have been influenced by the execution of the evaluation. With particular regard to the second task, field participants all worked through the task responding to each question, and after completing all tasks were then instructed to actually perform the task by following the journey information presented. Often by the time that the participant had completed the questions and were ready to commence the journey, the information displayed by the system was outdated (for example the system indicated that the user should catch a tram that had passed five minutes ago).

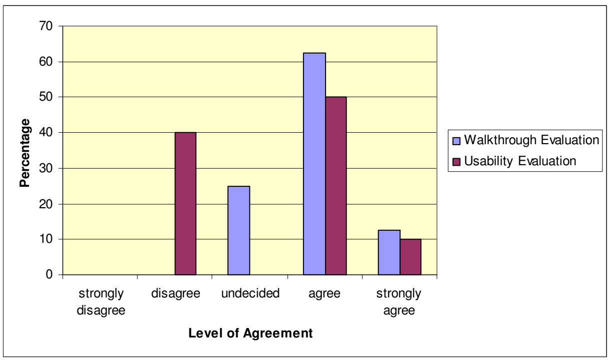


Figure 7-3 Perceived response time of system (by evaluation)

The response to the manual and automatic location capabilities of the system was also different between the two evaluations (refer to Figure 7-4). Walkthrough evaluation participants typically disagreed that positioning capabilities (either manual or automatic) were a concern. While the majority of usability evaluation participants concurred (with a higher proportion of participants strongly disagreeing in both cases), they were almost equally divided in their perspectives about automatic location capabilities. Manual location concerns were less significant, but still an issue for these participants.

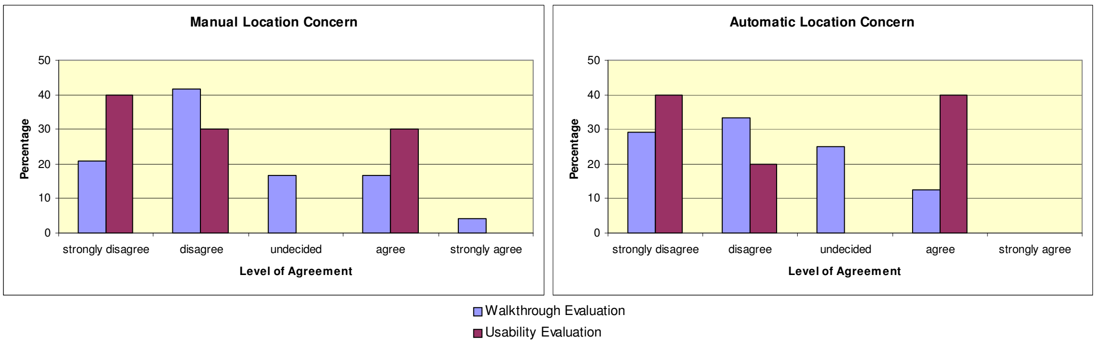


Figure 7-4 System location determination techniques (by evaluation)

The question referring to the potential for the application to provide more detailed information was strongly viewed as important by usability evaluation participants, while walkthrough evaluation participants typically agreed but responses were all spread across the full range of agreement levels (as shown in Figure 7-5).

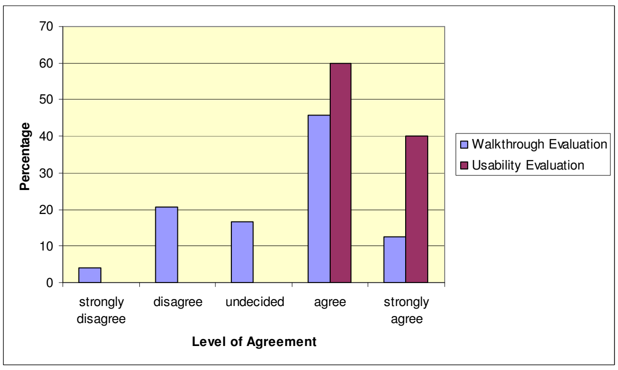


Figure 7-5 Desire for system to provide more detailed information (by evaluation)

At the conclusion of each task, usability evaluation participants were requested to complete a questionnaire to measure user performance and satisfaction with the application (refer to Section 10.3, Appendix C). Due to time constraints, very few field participants had time to complete task 4. As a result, task 4 responses were not included in the satisfaction and performance analysis. As can be seen from the average of the laboratory and field results shown below in Figure 7-6, the two contexts of use provided differing levels of satisfaction. Participants undertaking the evaluation in the laboratory had to conceptualise using the system in the real world and were generally more satisfied with the application, envisaging that it would be most useful. Those in the field, who used the system to physically complete the task, had differing responses with a general decline in the satisfaction and performance of the system over the duration of the tasks.

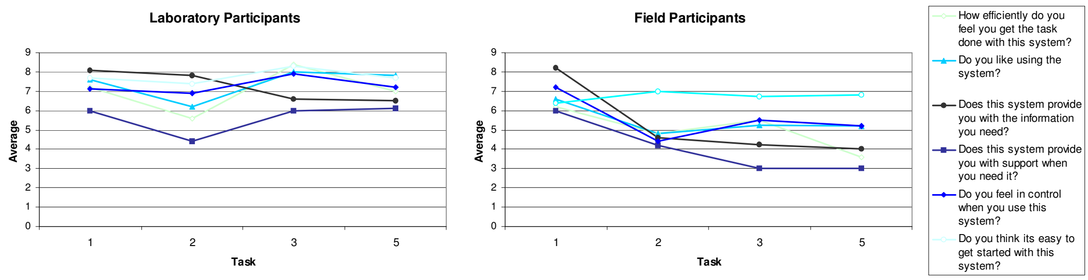


Figure 7-6 User performance and satisfaction (usability evaluation context)

These trends highlight the over optimistic response to the system by laboratory evaluation participants. Examining the different emphasis placed on the importance of the SDI requirements for the laboratory and the field participants in the usability evaluation, again reinforced the SDI requirements related to mobility. While many of the rankings were similar across the two contexts, three of the data issues were classified significantly differently: request handling, maintenance and quality (refer to Table 7-1). Request handling and data maintenance were both regarded as important by the field participants, but were only of minor importance to laboratory participants. Interestingly laboratory participants indicated that data quality was highly important whilst it was the least important requirement to field participants. Considering the strong correlation between maintenance and quality (good maintenance practices help to ensure the currency and quality of data available for the system) it is almost paradoxical that these requirements could be classified at the two extremes by both participant groups. This could be regarded as reinforcing the correlation between the two requirements in that since one of the requirements had been classified as important, the other requirement, although related, ended up as a low classification given that other requirements were deemed more important.

Table 7-1 SDI requirement ranking (usability evaluation context)

		Usability Evaluation	
	SDI Category	Field Rank	Laboratory Rank
Data	Content	2	2
	Standard/format	12	14
	Warehousing/indexing	13	9
	Archival	21	15
	Capture	22	16
	Request handling	9	22
	Scale	1	1
	Maintenance	4	17
	Restrictions	18	18
	Quality	23	5
Standards	Interoperability	6	8
	Consistency	5	4
	Metadata	14	19
	Data Format	16	10
Policy	Privacy	15	11
	Pricing	7	7
	Data standards	19	12
	Personalisation	8	6
Access	Data volume	20	23
	Data content	17	13
	Network	10	20
	Scalability	11	21
	Response time	3	3

Given that the walkthrough evaluation was similar to the laboratory based study in that participants did not have to use the system to physically complete tasks but only to obtain travel information, and had to conceptualise this information in the context of the real world, the effect on the choice of SDI requirement rankings was expected to be similar between these end user participants. Indeed the difference between the walkthrough evaluation rankings and the laboratory rankings was small, with no significant discrepancies observed. Comparing the two evaluations as a whole once more identified only three requirements that were ranked significantly differently: content (data), standard/format (data) and data standards (policy); refer to Table 7-2. Walkthrough evaluation participants regarded data content and the data standards from a policy perspective as important, but these issues were regarded as significantly less important by the usability participants; in particular, content received the lowest rank by the usability evaluation participants. Usability participants did however rate the file type and structure of a data set (standard/format) as important, while this was seen as less important by walkthrough participants.

Table 7-2 SDI ranking (walkthrough and usability evaluations)

	SDI Category	Walkthrough Evaluation Rank	Usability Evaluation Rank
Data	Content	10	23
	Standard/format	22	6
	Warehousing/indexing	17	10
	Archival	21	22
	Capture	23	23
	Request handling	20	15
	Scale	5	1
	Maintenance	9	8
	Restrictions	19	20
	Quality	1	9
Standards	Interoperability	4	7
	Consistency	10	4
	Metadata	12	16
	Data Format	11	17
Policy	Privacy	8	11
	Pricing	6	6
	Data standards	7	19
	Personalisation	13	5
Access	Data volume	18	21
	Data content	16	18
	Network	14	12
	Scalability	15	13
	Response time	2	3

The differing emphasis placed on requirements from the evaluations could be attributed to other characteristics of the evaluation participants. Therefore several participant categorisations were explored to identify additional trends, and link them to the SDI people categories.

7.3 Participant Categorisation

Based on questionnaire responses from participants, it was possible to categorise them according to their SDI People Category, by gender, by technical ability or by spatial ability.

As described in Section 4.5.1 participants representing the spatial industry were presented with a specific question on their questionnaires asking them to classify the role of their department or organisation as a data provider, application developer or integrator, or as a combination of the two. Participants not representing an organisation were classified by default as end users and were not required to answer this question. All participants for the usability evaluation were also classified as end users.

Table 7-3 summarises the criteria by which participants were classified. The categories were considered to be mutually exclusive; that is classification of a participant as ‘technical’ held no bearing on their classification as either ‘spatial’ or ‘non-spatial’.

Table 7-3 Participant categorisation criteria

Category	Questionnaire Criteria	Classification	No. of Participants
Gender	Personal details	Male Female	19 15
SDI People Category	Q15	Data Provider Application Integrator Both (Data Provider and Application Integrator) End User	2 5 6 21
Technical Ability	(Q1a) Minimum frequency of work related computer use: weekly (Q1b) Minimum frequency of recreational computer use: than less than once per week (Q4) Minimum Internet frequency use: weekly (Q7) At least two services used on mobile phone	Technical	15
	Participants not classified as technical	Non-technical	19
Spatial Ability	Response to Q10 OR response of very confident to all tasks in Q11	Spatial	20
	Participants not classified as spatial	Non-spatial	14

Gender

Gender comparisons are common in many studies related to spatial ability due to the perception of male and female differences in spatial processing (Medina, Gerson & Sorby 1998; Dabbs et al. 1998; Silverman & Eals 1992; Hunt & Waller 1999). While it was not the purpose of this research to evaluate gender differences in spatial information processing, it was interesting to compare the responses to the question relating to ability of spatial tasks. The comparisons shown in the graph below (Figure 7-7) are based on user responses in their confidence to complete such tasks (as opposed to a more rigorous approach which would have conducted experiments in relation to these tasks) and thus it is difficult to ascertain whether the responses are an accurate representation of actual spatial ability or reflect other psychological characteristic differences between gender.

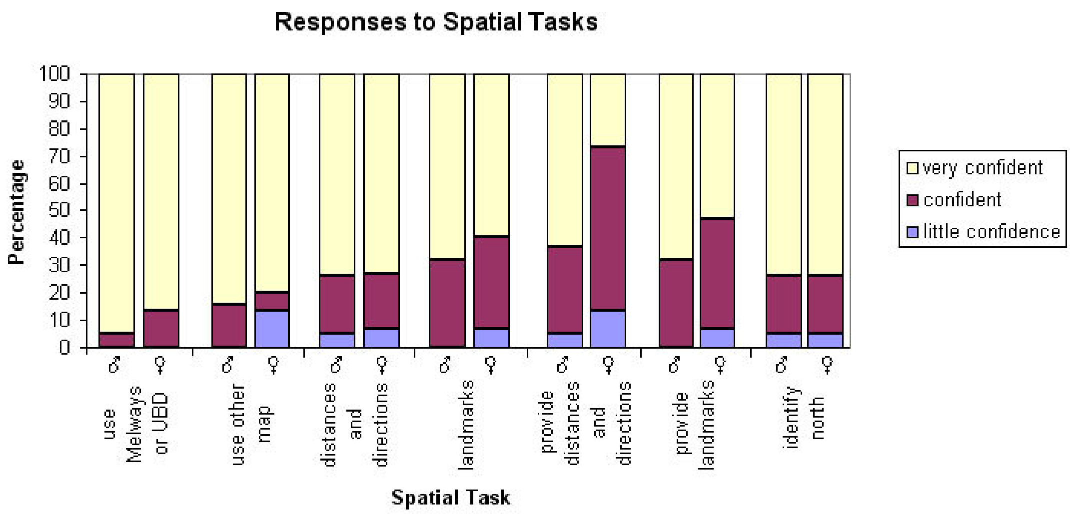


Figure 7-7 Spatial task confidence (by gender)

Across the categories defined to measure application use, male and female responses were very similar with no significant discrepancies observed. Across the SDI requirement rankings, females ranked scale, data format, consistency and pricing higher than males; the male responses were more distributed across all categories, but in general males ranked interoperability and privacy higher than females.

SDI People Category

The responses to application use were evenly distributed across each of the SDI people categories with end users typically identifying more of the usability related issues (such as timeliness of system response and logical interface flow). It was interesting to observe the similar perspectives across data producers, application developers/integrators, or participants who covered both categories. Across the SDI requirements, the different perspectives were more prominent with the top five rankings by each user type shown in Table 7-4.

Table 7-4 SDI requirement rankings by SDI people category

	SDI People Category			
Rank	Data Provider	Application Developer	Both	End User
1	Quality, Pricing	Content	Content	Quality
2	Content, Data Format	no clear leader	Quality	Response Time
3	Personalisation, Network	no clear leader	Scale	no clear leader
4	Maintenance, Quality	Data Format	no clear leader	Maintenance, Consistency
5	Restrictions, Response Time	Maintenance, Data volume	Capture, Scalability	Interoperability, Pricing

Technical

The trends observed between technical and non-technical participants on the application use were extremely similar with no major differences observed. The differences in overall rankings reflect the more user-oriented focus of those classified as non-technical, and the more implementation specific focus of the technical participants.

Table 7-5 SDI requirement rankings from technical and non-technical participants

Rank	Technical	Non-technical
1	Content, Quality	Quality
2	Response Time	no clear leader
3	no clear leader	Scale, Response Time
4	Consistency	Privacy, Response Time
5	Interoperability	no clear leader

Spatial

The distribution of agreement statements across each of the application response areas was fairly even between spatial and non-spatial participants. A higher proportion of spatial participants strongly agreed with statements regarding information quantity, usefulness of information, expected information and appropriateness information compared with non-spatial participants. Non-spatial participants strongly agreed on the usefulness of information, interface logic, more detailed information and accurate information. The ranking of SDI requirements reflected more generic, usability issues from non-spatial participants and more technical or implementation focused issues from spatial participants. This view is somewhat distorted due to the majority of non-spatial users who participated in the evaluations.

Table 7-6 SDI requirement rankings from spatial and non-spatial participants

Rank	Spatial	Non-Spatial
1	Quality	Content
2	Response Time	Scale
3	no clear leader	Personalisation
4	Consistency	Response Time
5	no clear leader	Scalability

7.4 Discussion and Evaluation

Both the theoretical evaluation and the practical development and evaluation of the prototype identified a number of issues related to LBS for each of the SDI components. The components and their corresponding issues are discussed below in the context of each of the SDI people categories.

7.4.1 Data Provider

The issues relevant to data providers (responsible for capturing data and providing it in appropriate forms for those who wish to use it), and their relative importance are shown in Figure 7-8 – the darker the shading, the greater the importance. From the perspective of a data provider, the access network refers to the channels via which they provide their data. Typically this is achieved via wired communication media (such as fixed line Internet). Data providers need to develop policies dictating the use and access of their data, and adopt and conform to standards to ensure interoperability with other data sets and systems.

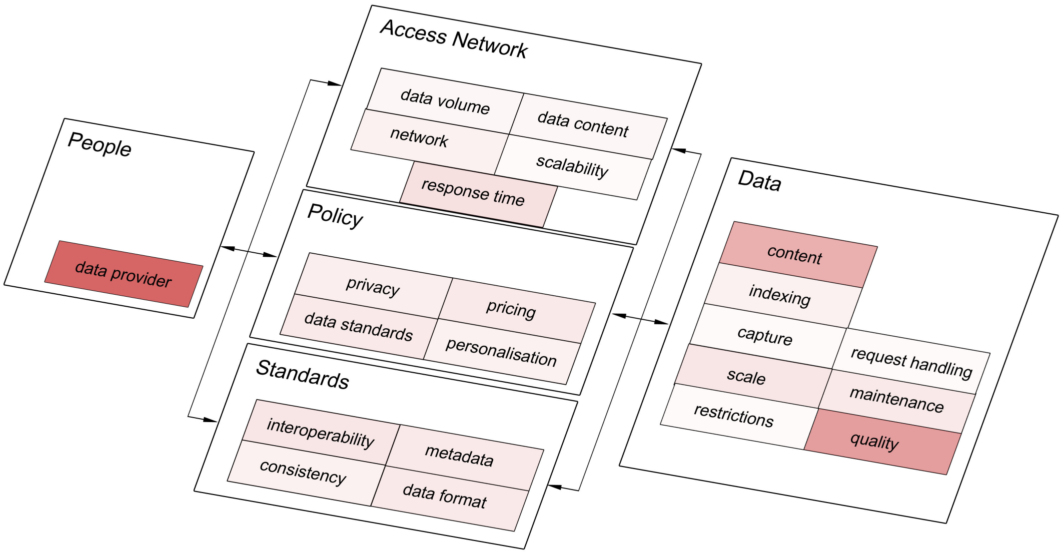


Figure 7-8 Expanded SDI model – data provider perspective

Data

As is expected, the data component was identified as the most important for data providers with two issues ranked most highly by evaluation participants:

- the characteristics of a data set that bear on its ability to satisfy stated and implied needs (quality); and
- the real world entities and their interactions as represented in a particular data set (content) ranked most highly by evaluation participants.

Both the public and private sectors are involved in the provision of various data sets for many purposes. For the prototype, data was primarily obtained or accessed from two data providers – the Victorian Government Department of Infrastructure and Sensis. DOI contributed spatial data sets representing the relationships between tram stops and tracks. The data was provided in industry format files using a standard projection system facilitating integration with other data sets. The data representation however lacked the topology required for network modelling and routing. Provided without metadata, it was difficult to ascertain how the data was originally captured and to assess each of the data quality elements. Upon clarification of these issues with DOI, it was determined that the stop positions had been updated using GPS techniques, with the last updates being completed in June 2002. The positional accuracy of stop positions appeared to be planimetrically accurate to within 10 metres (based on data overlays and handheld GPS positioning of several stops). The logical consistency, which assumes consistent measurements will yield similar values when repeated many times, proved to be quite poor with individual lines (that varied in their position) used to represent each tram route despite them being physically coincident in the real world. As with many data sets, typographical errors and missing entries for a small proportion of attributes were evident.

Spatial data in the form of maps, and pedestrian navigation instructions was accessed from Sensis' Whereis Location Server. The pedestrian navigation information was calculated from origin and destination coordinate pairs, one of which matched with the coordinates of a tram stop. In some instances, due to errors in the positioning of tram stops, incorrect navigation instructions were returned by the system. This led to a number of field usability evaluation participants encountering problems when completing tasks. In particular, task 2 required field participants to travel to the intersection of Little Collins and Exhibition Streets (refer to Section 10.2, Appendix B). The system suggested disembarking the tram at the corner of Bourke and Exhibition Streets and walking to Little Collins Street. However due to a positional inaccuracy of the tram stop at the corner of Bourke and Exhibition Streets, the navigation instructions recommended that participants turn left down Exhibition Street. Since participants were disembarking at the physical tram stop, following these instructions would lead them away from Little Collins Street, rather than towards it as shown in Figure 7-9.

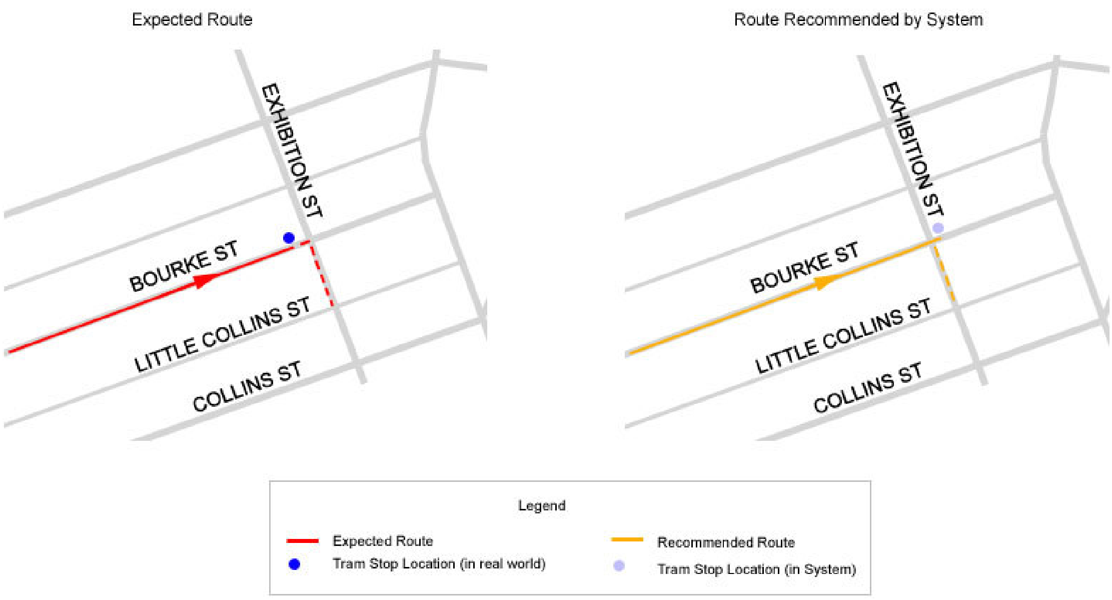


Figure 7-9 An example of the importance of data accuracy

Standards

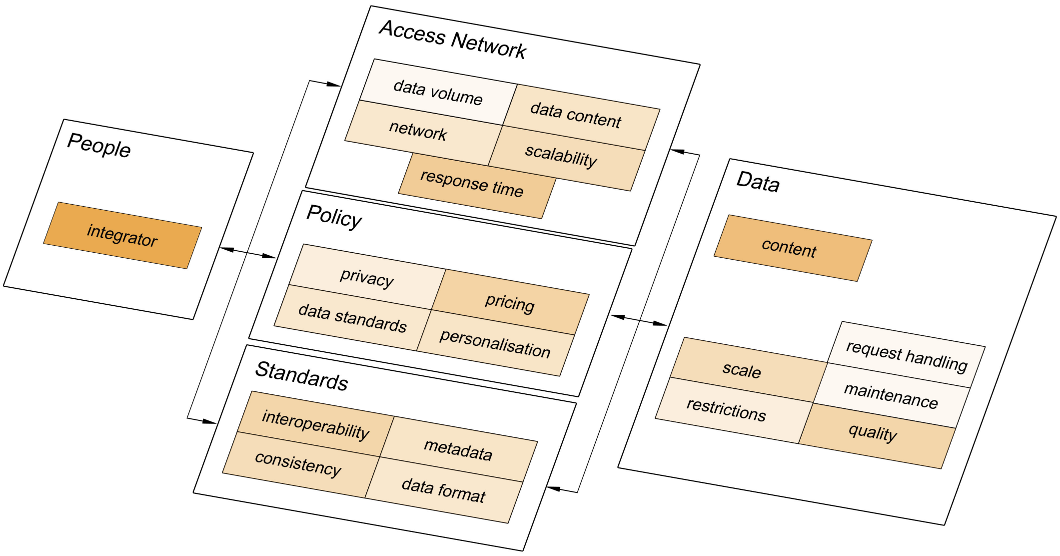
The standards component also plays an important role for data providers in an SDI. Since the data was provided using industry standard file formats and projections, integration with other data sets and software systems was easily achieved. The lack of data quality statements and metadata did not help to demonstrate that standards had been adopted.

The API used to access the Whereis Location Server uses standard HTTP requests and returns responses in XML. An attempt to create a standard API (with standardised commands for spatial queries) has been undertaken as part of the OpenLS initiative. Webraska, who provide the API to access Sensis' data have been one of the lead sponsors and editors of the specification along with organisations from all aspects of the LBS industry (Spinney 2003).

7.4.2 Integrator

Integrators or application developers are responsible for combining data sets and developing applications and interfaces to facilitate access and use by end users. The integrator's role is more evenly distributed across the five SDI components (refer to

Figure 7-10) than the data provider SDI model, although the data component and the issue of content remained the most prominent. The focus of the components from the perspective of an integrator introduces the needs of end users and the usability requirements of applications using data. For these reasons, the content, scale and quality of data are paramount, standards and policy issues also remain highly important with the issues of interoperability and pricing particularly so. The most important issue within the access network is that of response time; ensuring end users timely access to data sets, and the information that they require.



Darker shading indicates greater importance

Figure 7-10 Expanded SDI model – integrator perspective

Data

While the data from DOI did utilise a standard industry format, conversion was required in order to format and restructure the data for the purposes of network traversal. These modifications could have an impact on data maintenance policies; if DOI provide updated data on a regular basis this conversion procedure would have to be applied for each update.

A common datum and projection for all data employed by the system was also required. Given the remote location of the Sensis data, the locally stored public transport data was converted to the projection and datum of the Sensis data.

The prototype construction highlighted the inadequacy of ‘spaghetti’ data sets (vector data composed of line segments which are not topologically structured or organised into objects and which may not be geometrically clean) for topological modelling. For integrators combining data sets and developing navigational LBS, much work may be involved in the preparation of topology for networking purposes. Additionally the management of large data sets, and their subsequent segmentation and restructuring to present meaningful information to mobile users requires significant effort.

Access

As identified earlier, human-computer interaction within the mobile environment is an important issue. The first levels of the proposed hierarchical information structure were implemented in light of these constraints. The hierarchy levels proved somewhat frustrating to evaluation participants who expressed a desire for graphical and textual information to be available on the one screen. These suggestions can be partially attributed to the properties of the iPAQ device used in the evaluation. Whether this issue would be as prominent for mobile phone users of the system remains to be determined. Thorough user requirements analysis and a user centred design methodology could have resulted in an improved information structure interface flow for the application.

In addition to presenting minimal, but sufficient, information to a user conducting various tasks, the response time of the application and its ability to handle multiple simultaneous requests are also of significance. Implementing the application and demonstrating it using a live GPRS data connection helped to accurately represent the response times and data rates achievable of LBS. Walkthrough evaluation participants tended to be satisfied with the response time of the application, while usability participants (particularly those performing the evaluations in the field) felt a strong sense of time pressure.

Standards

The prototype application required standard interfaces to link the various software components; the back-end algorithm implementations needed to be compatible with the Internet and the mobile devices on which the application could be accessed. Developments such as the APIs proposed by OpenLS and the Location Interoperability Forum will help to facilitate LBS application development through the provision of standard interfaces, tools and components to LBS application developers/integrators (Spinney 2003).

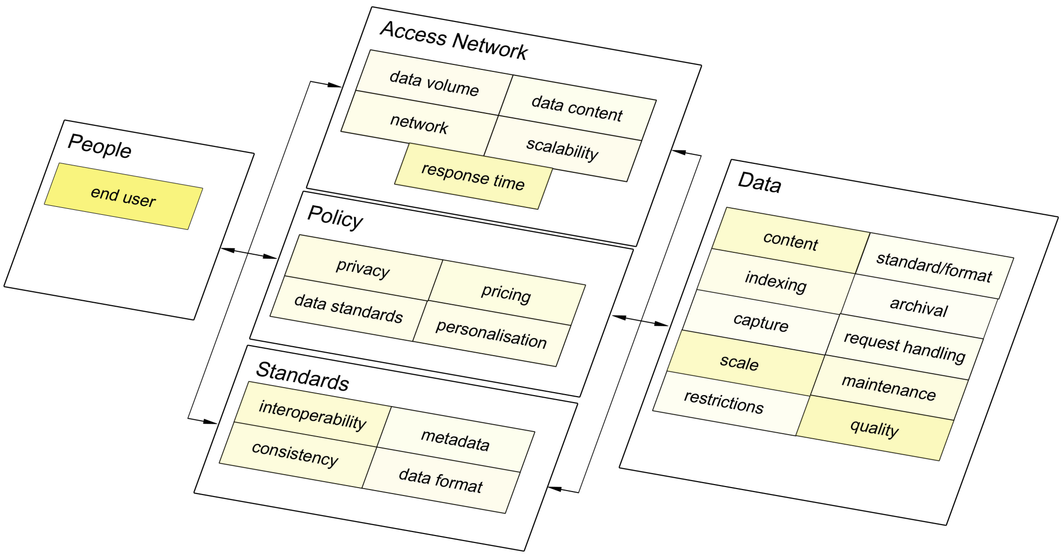
Data quality was directly dependent on the data provider. Alterations that were made to the public transport data set were for networking purposes and aimed to enhance the logical consistency of the data sets. Since no metadata records existed, no particular metadata standard was preferred over another. Metadata records were established for the modified data sets using ANZLIC's metadata guidelines (compatible with ISO/DIS 19115) designed for the Australian Spatial Data Directory.

Policy

Falling within the responsibility of the integrator are policy issues related to privacy and personalisation. With the ability to tailor services to a user's location and the time of day, LBS potentially enable a very detailed 'digital persona' to be constructed which can be used to determine the nature of a person's activities through the analysis of time (including frequency and duration). It would then be possible to identify common signatures of spatio-temporal behaviour and link this to socio-economic data. However, issues of personalisation are also critical to the adoption of such services in terms of cognitive ergonomics (Carroll, Kellogg & Rosson 1991) and interaction design. The prototype did not offer any personalisation features, although the ability to store common locations or frequently used tram routes (for rapid timetable lookup) was an area of improvement suggested by several evaluation participants. The prototype did not impact on user privacy any more so than the existing ability of the wireless telecommunication network to trace the location of mobile phones.

7.4.3 End User

End users can benefit from SDI based applications without any knowledge or understanding of the underlying infrastructure required to deliver them. Assessing their requirements in terms of the SDI components reveals a strong importance placed on data and the access network as shown in Figure 7-11. Issues of data quality and content remain important as for the other SDI people categories, however the issue of scale referring to the size and level of detail of spatial information is also highly valued. Rather than specifying the guidelines for data access and use, end users are subjected to the specifications of the issues made by the integrators and data providers. The access network dictates how users can gain access to the information they require, and response time remains an important issue for this user group. End users rely on appropriate standards being in place to ensure that the application is interoperable with other systems and data, so that it may present to them the information that they require (e.g. integrated spatial and routing information from distributed sources, perhaps with links to commercial or transactional sites).



Darker shading indicates greater importance

Figure 7-11 Expanded SDI model – end user perspective

Data

The nature of mobility implies specific characteristics in terms of data content that is delivered to users. Mobile users do not want to be overloaded cognitively, rather they need relevant and timely information that is easy to read and comprehend. Users appreciate data that is highly accurate and reliable, reducing the cognitive load associated with evaluating and interpreting it. As mentioned previously, input items need to be clear, allow for easy data entry, and not require onerous activity in relation to the resulting information that is displayed. The prototype helped to minimise data input through the use of GPS positioning which could be used as a journey origin. The textual entry of street and suburb names proved challenging for some participants; a graphical input representation could perhaps offer an easier solution.

Access

As discussed previously, issues from an end user's perspective are related to interaction with the service in competition with other tasks. Users do not want their service interaction to be time consuming nor impeded by other concurrent users.

Policy

The issues of personalisation and privacy are of particular relevance to end users. Application providers need to give their assurance that the end user's position and activities related to the use of the application are not tracked, recorded or provided to any third parties without their permission.

7.5 Expanded SDI Model

While this research has utilised a public transport application as an example LBS to demonstrate some of the issues associated with wireless application development and deployment, and to explore these issues in the context of SDI, the resulting expanded SDI model is intended to remain fairly generic and hence be applicable to other LBS areas.

The relative importance of the issues shown in the expanded model from each of the perspectives, whilst directly evolved from the public transport application still seem relevant in a more general context. For example, consider a location based traveller information service that included:

- Positioning (including a map of the surrounding area);
- Service finder -
    - return list of businesses, restaurants, subway stations etc. given a list of criteria;
    - filter information for distance, product type, venue type, cuisine type, etc.;
    - maps and turn-by-turn instructions for the returned information; and
- Request an additional service (e.g. taxi, police) to the current position.

(Rich 2003)

Data quality and content would remain a high importance for data providers (potentially a large number in this situation). The service integrator would still need to ensure and verify the data content, scale and quality, ensure that it was structured in a manner to facilitate request handling, and accommodate any restrictions on information access or querying (e.g. perhaps some users should be prohibited from searching for venues of specific types). The interoperability of all data sets would be paramount in this example, with issues of consistency, data format and metadata also playing an important role. The end user would require a service that responded promptly, was accessible over an appropriate communication channel or network, and that presented appropriate quantities of information in relevant presentation formats. The price set to access the service would have to balance the perceived value obtained by the service. The privacy and personalisation features of the service would have to be deemed appropriate. Finally, the standards in place and used by the data providers and the application integrator would ensure the overall smooth running and efficiency of the service.

In order to fully verify the model's general applicability for the service described above and others, additional research is required. In some implementations perhaps not all of the issues identified will be relevant. Conversely, additional issues that have not arisen from this research should not be excluded from an expanded SDI model for wireless information access and dissemination. The model should provide an initial check list for representatives of each of the SDI people categories and should remain somewhat flexible and dynamic.

7.6 Hypothesis Testing

The hypothesis (developed in Chapter 4) stated that:

> Expanding the SDI model in terms of potential user categories for wireless LBS will identify additional features that support wireless, real-time, spatial decision making.

The development of the prototype for public transport information and guidance was representative of a wireless LBS application intended to support real-time, spatial decision making by users. The research undertaken in order to develop the prototype identified from a theoretical perspective, a number of areas where the current SDI model was lacking when applied in the wireless environment.

The two evaluations conducted using the prototype demonstrated the importance of user interface and usability design for wireless applications and allowed for the analysis of theoretically identified additional requirements for the SDI model. The requirements were ranked by participants representing each of the SDI people categories reflecting their relative importance.

As discussed in the previous section, the evaluation of the SDI model and prototype contributed to the development of an expanded SDI model (Figure 7-12, refer to Figure 7-8, Figure 7-10 and Figure 7-11 for the layer details), with the expansion taking the form of an additional level of detail for each of the SDI model components.

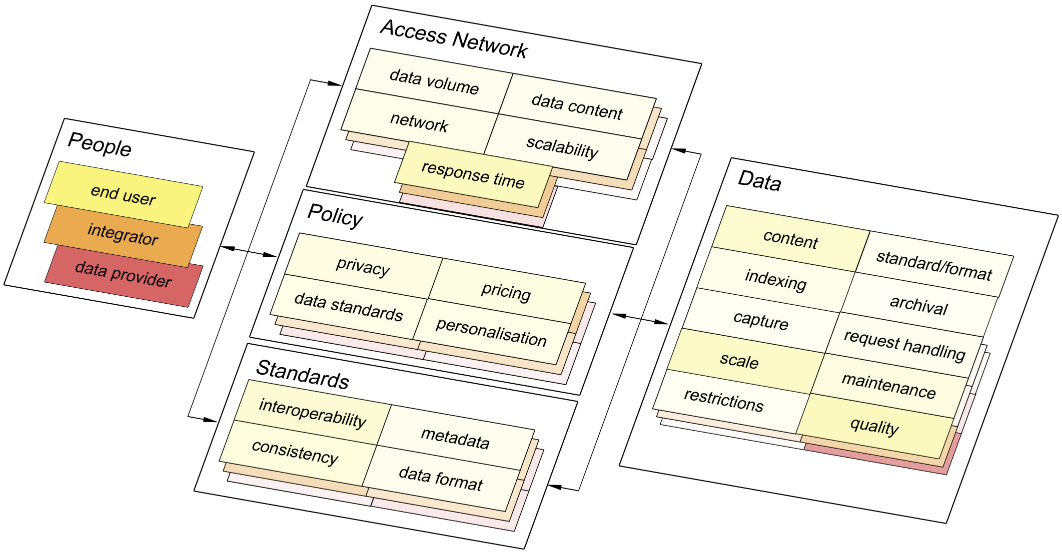


Figure 7-12 Expanded SDI model for LBS

The identification and verification of additional SDI requirements specifically for wireless LBS demonstrate the acceptance of the hypothesis. The applicability of this expanded model for other LBS examples (discussed briefly in the previous section) still requires further verification in order to ensure its completeness.

7.7 Conclusions

This chapter has discussed the two evaluations carried out, highlighting the differences between the results obtained from both. The usability evaluation, and in particular the field evaluation, identified the importance of many issues associated with usability and mobility of users. The walkthrough evaluation provided a broader perspective, yet formed the basis for the SDI people categories and contributing issues in the final expanded SDI model.

The expanded SDI model, encompassing the three SDI people categories of data providers, integrators and end users identifies a number of issues (and their relative importance) that should be considered when developing an LBS application. The model has been based directly on the evaluation findings from this research which utilised a public transport information LBS, but the identified issues remain general and applicable to other LBS areas. As a result, the hypothesis for this research was accepted.

The next chapter concludes the research, drawing the final conclusions.

Chapter 8 Conclusions/Recommendations

The objective of this chapter is to document the major findings from the research in terms of the aims and approach outlined in Chapter 1 and Chapter 4.

This chapter provides conclusions to the aims of the thesis, and details the areas recommended for further research.

8.1 Conclusions

SDIs provide an effective framework in which to explore the set of interrelated issues that collectively govern the quality of service delivery in LBS. Although data access and dissemination through SDI has previously been considered with a focus on wire line communication methods, the basis of the theoretical principles remains constant when moving to the wireless environment. People still require access to data sets, and the access is achieved through the establishment of appropriate networks, standards and policies. It is the specifications for these components that require modification to accommodate the successful delivery of LBS.

This research successfully achieved the aim of determining the additional features required for the SDI model in order for it to support wireless, real-time, spatial decision making in the form of LBS through the culmination of the identified objectives:

- Evaluating the SDI model in terms of its applicability to wireless LBS;
- Identifying, at a theoretical level, expansions to the SDI model for it to support wireless LBS;
- Developing a working prototype LBS;
- Evaluating the prototype LBS in terms of the proposed expanded SDI requirements and the usability of the application; and
- Using the prototype evaluations to revise the SDI requirements and developing an expanded SDI model that supports wireless LBS.

Examining additional features for the SDI model in order for it to support wireless, real-time, spatial decision making through a practical implementation of an LBS proved to be an effective way in which to demonstrate the SDI concept. Gaining participation from people representing each of the SDI people categories identified those issues that were relevant to each of the categories, and a relative ranking of the importance of each. While many of the issues were relevant to more than one of the SDI people categories, the shift in emphasis across the categories was interesting to observe. The strong interconnection and correlation between the five model components has been reinforced through the additional issues identified and their relevance to multiple SDI people categories.

The dual evaluation approach was very insightful, providing perspectives on both the usability of the system as a mobile LBS application, as well as focussing on the underlying theoretical issues. The usability evaluation was particularly useful in identifying the skewed responses from participants evaluating the system in a hypothetical situation as opposed to the real world.

The expanded model developed from the research should behave as an example framework for future LBS implementations. Rather than specifying a complete and exhaustive list of issues related to wireless, spatial application deployment, the model can act as a starting point, or check list of issues that should be considered. In some implementations, the emphasis of the issues may change, additional issues may arise and some issues may not be of importance at all. Despite this, the model provides a common starting point for LBS applications.

Like many other software applications it can be a challenge to implement and move an LBS to a 'live production' stage. Sourcing and gaining access to relevant data sets are just one of the challenges faced by application developers. The partnerships and data access arrangements that exist for various SDI initiatives offer a valuable resource for LBS developers. Adapting the SDI model so that it can support wireless spatial information dissemination is just one step on the path to improving access to spatial information.

8.2 Recommendations

The expanded SDI model has been derived from a specific example of an LBS. Ensuring that the expanded model is applicable to other LBS applications and categories requires further research. Indeed refinement of the model will probably involve continual evolution, inline with technological advances. In particular, the evolution of the expanded SDI model is likely to encompass issues surrounding:

- the criticality of information (assessing the impact of real-time information on existing user plans);
- time/space indexing (indexing data for fast retrieval and delivery of 'user centred' data);

- data conflation (integration of fine scale, time critical, ephemeral, spatial and a-spatial data);
- data formats (support of integration and rendering of information in a range of presentation formats: text, sound, maps, 3D, spoken instruction, photographs, video sequence);
- data quality (assessing the impact of lineage, positional accuracy, attribute accuracy, logical consistency, completeness and temporal accuracy on user plans); and
- customisation (ease of tailoring interaction and presentation of information).

8.3 Summary of Contributions

This research has contributed an expanded SDI model that supports the real-time dissemination of spatial information over wireless devices. This model is of relevance to both the spatial information industry and participants in the wireless application development domain. As discussed above, this model provides an example framework for LBS development and deployment.

It is important to note that this research has been widely disseminated within the academic and government sectors and has resulted in two journal publications (Smith, Kealy & Williamson 2002; Smith et al. in press) and a book chapter (Smith & Kealy 2003).

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Chapter 10 Appendices

10.1 Appendix A – SDI Model Evaluation Questionnaire

The following questionnaire was presented to all evaluation participants. Question 15 was omitted for participants who were initially identified as end users.

Section 1 - Personal Details

Gender:	☐ Male	☐ Female		
Age:	☐ 18 – 25	☐ 26 – 35	☐ 36 – 45	☐ over 45
Occupation:	______________________			

Section 2 - Computing/Technology Experience

This section of questions relates to your experience and use with computing and mobile computing devices.

Q1. In the recent past, how often have you used a computer?

	never	less than once per month	less than once per week	weekly	daily
For work/study purposes	☐	☐	☐	☐	☐
For recreational purposes	☐	☐	☐	☐	☐

Q2. Please indicate your confidence in your ability to use the following software packages:

	very confident	confident	little or no confidence
Word processor	☐	☐	☐
Graphics/drawing package	☐	☐	☐
World Wide Web Browser	☐	☐	☐
Email	☐	☐	☐
Spreadsheet	☐	☐	☐
Database	☐	☐	☐

The following questions relate to your use of the Internet or World Wide Web. If you have never used the Internet, please go to the next page.

Q3. Where have you used the Internet? *(Please check all that apply.)*

- ☐ At home
- ☐ At a relative or friend's home
- ☐ At place of work/study
- ☐ At a commercial location e.g. cyber café
- ☐ At a public place e.g. library
- ☐ Other ____________________

Q4. How often do you usually use the Internet?

- ☐ Less than once per month
- ☐ Less than once per week
- ☐ Weekly
- ☐ Daily

Q5. What do you primarily use the Internet for? *(Please rank your top three uses with 1 indicating primary use.)*

- ☐ Education
- ☐ Shopping/Gathering product information
- ☐ Entertainment
- ☐ Banking
- ☐ Work/Business
- ☐ Communication with others (not including email)
- ☐ Gathering information for personal needs
- ☐ Passing time
- ☐ Other ____________________

The following questions relate to your use of a mobile phone. If you do not own or use a mobile phone please go to the next section.

Q6. In addition to your mobile phone, do you own or use any other mobile devices on a regular basis? *(Please check all that apply.)*

- ☐ Digital Organiser/Diary
- ☐ Personal Digital Assistant (e.g. Palm Pilot, iPAQ)
- ☐ Other ______________________________

Q7. What services do you use on your mobile phone? *(Please check all that apply.)*

- ☐ Voice calls
- ☐ SMS
- ☐ Picture messaging
- ☐ Games
- ☐ Alarm/Event notification

The following questions relate to the Internet or WAP capabilities of your mobile phone. If you have never used the Internet on your mobile phone please go to the next section.

Q8. How often do you use the Internet on your mobile phone?

- ☐ Less than once per month
- ☐ Less than once per week
- ☐ Weekly
- ☐ Daily

Q9. Please indicate your confidence in your ability to use the Internet on your mobile phone:

- ☐ Very confident
- ☐ Confident
- ☐ Little or no confidence

Section 3 – Spatial Experience

This section of questions relates to your experience and confidence in dealing with spatial information.

Q10. Did you study Geography or Geomatics related courses beyond school? *(If so, please indicate the course name.)*

☐ Yes

Course: ______________________________

☐ No

Q11. Please indicate your confidence in your ability to:

	very confident	confident	little or no confidence
Use a Melways or UBD map	☐	☐	☐
Use a map other than Melways or UBD	☐	☐	☐
Follow route directions using distances and directions	☐	☐	☐
Follow route directions using landmarks	☐	☐	☐
Provide route directions using distances and directions	☐	☐	☐
Provide route directions using landmarks	☐	☐	☐
Identify north orientation	☐	☐	☐

Section 4 – Public Transport Information Service Application

The following questions relate to the Public Transport Information Service application. This application can be used to find routes between an origin and destination (either for immediate or future travel) or to check the timetable for a particular tram route.

Q12. Please indicate your level of agreement with each of the following statements:

	strongly agree	agree	unsure	disagree	strongly disagree
The application provided the information that I was looking for.	☐	☐	☐	☐	☐
The application provided information that I expected.	☐	☐	☐	☐	☐
The application provided information that I could use to travel from an origin to a destination.	☐	☐	☐	☐	☐
The interface was logical.	☐	☐	☐	☐	☐
Information was presented in a timely manner.	☐	☐	☐	☐	☐
Each screen of information contained too much information.	☐	☐	☐	☐	☐
The privacy implications of this application worry me.	☐	☐	☐	☐	☐
I have concerns about a service which is based upon *automatically* knowing my location.	☐	☐	☐	☐	☐
I have concerns about a service which is based upon *manual* entry of my location.	☐	☐	☐	☐	☐
I would be willing to subscribe to this sort of service.	☐	☐	☐	☐	☐
I would be willing to pay for this service each time I used it.	☐	☐	☐	☐	☐
I would like more detailed information from the application.	☐	☐	☐	☐	☐
The application provided accurate information.	☐	☐	☐	☐	☐

Q13. A number of issues have been identified throughout the development of the application. From the perspective of your department/organisation, could you please rank the top five most important issues from 1 through to 5 (with 1 denoting the most important issue).

Data	Content	The real world entities and their interactions as represented in a particular data set.	☐
Data	Standard/format	The file type and structure of a data set.	☐
Data	Warehousing/indexing	'Shortcut' methods to expedite data access.	☐
Data	Archival	Backing up and storage of the system and associated data.	☐
Data	Capture	The method by which data sets are constructed, formed or compiled.	☐
Data	Request handling	The process of interrogating data sets to obtain relevant information.	☐
Data	Scale	The size and level of detail of map information displayed.	☐
Data	Maintenance	The method by which data is updated and system integrity maintained.	☐
Data	Restrictions	Pricing or other restrictions (e.g. privacy) on data sets.	☐
Data	Quality	Totality of characteristics of a product that bear on its ability to satisfy state and implied needs. Specifically: lineage, positional accuracy, attribute accuracy, logical consistency, completeness and temporal accuracy	☐
Standards	Interoperability	Capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units.	☐
Standards	Consistency	The use of familiar and similar patterns in the system.	☐
Standards	Metadata	Data describing data.	☐
Standards	Data Format	The file format of a geographic data set – industry standard?	☐
Policy	Privacy	Storage and use of location information gathered through use of the application.	☐
Policy	Pricing	Pay per use, subscription fee or other model for both the application and the underlying data sets.	☐
Policy	Data standards	Restrictions on the use of data that doesn't conform to industry standards.	☐
Policy	Personalisation	The ability of an application to be customised by a user (either manually or based on repeated use).	☐
Access	Data volume	The quantity or amount (in bytes) of data that is sent in a particular request-response pair.	☐
Access	Data content	The form, entities and entity relationships of the information presented to the user.	☐
Access	Network	The physical transmission mechanism used to transfer data to the user (In this case a combination of GSM or GPRS and the Internet.)	☐
Access	Scalability	A measure of how many people can access the service simultaneously.	☐
Access	Response time	The time elapsed between a user request and a response.	☐

Q14. Are there any other issues that your department/organisation would regard as important that are not identified in the table above?

____

____

____

Q15. How would you classify your department/organisation?

- ☐ Data provider
- ☐ Application/data integrator

Section 5 – General Comments

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Thank you for your cooperation in this research project.

10.2 Appendix B – Usability Evaluation: Tasks

1. You are going from Swanston and Flinders Street to Toorak and Chapel Street later today. You know that tram route 8 will take you there and that you should board the tram at stop 32 and get off at stop 14

   Using the "timetable lookup" option, find out:

   a. Three alternative departure times around 16.30
   b. When the next tram is leaving

   When you have completed the task, return to the startup screen.

2. You are going to catch a tram from the corner of Swanston and Queensberry Street in Carlton for a meeting at the corner of Little Collins and Exhibition Street in Melbourne. You have to be there in about 30 minutes from now.

   Using the "plan trip" option, find out:

   a. Which tram route(s) to take
   b. When the first possible tram is departing
   c. The number of route changes (if any)
   d. If there is a route change, where to board the second tram.
   e. Which stop to get off the last tram.
   f. How to get from the last stop to your final destination.
   g. The estimated time of arrival.

   Use this information to get to the meeting.

   When you have completed the task, return to the startup screen.

3. You are at Federation Square in Melbourne. You want to go to Colonial Stadium. You have arranged to meet some friends at the corner of Spencer and Bourke Street in Melbourne.

   Using the "determine route" option, find out:

   a. Which tram route(s) to take
   b. When the first possible tram is departing
   c. How to get to the tram stop from your current location

   Use this information to get to Colonial Stadium.

   When you have completed the task, return to the startup screen.

4. You are at Gate 2 of Colonial Stadium. You have arranged to meet some friends at *Pizza Hut* in Bourke Street Mall.

    a. Use the system to get there within the next 20 minutes
    b. How long will it take you to get to *Pizza Hut*.

    Use this information to get to *Pizza Hut*.

    When you have completed the task, return to the startup screen.

5. You have finished eating. You are at Bourke Street Mall and want to return to the main entrance of Melbourne University.

    a. Use the system to get there as soon as possible

    When you have completed the task, return the device to the evaluator.

10.3 Appendix C – Usability Evaluation: User Performance and Satisfaction

UD-Scale (ISO 9241-11, 1993)

Please read each of the following questions. Circle the number that best indicates how near or how far you think the system you are rating is from the two extremes indicated.

How efficiently do you feel you get the task- done with this system?

Badly: the system keeps on getting in the way.	1	2	3	4	5	6	7	8	9	Well: work goes very efficiently.

Do you like using this system?

No: It is very stressful and unpleasant to use.	1	2	3	4	5	6	7	8	9	Yes: I really enjoy using it.

Does this system provide you with the information you need?

No: There's never enough information when you need it.	1	2	3	4	5	6	7	8	9	Yes: All the information I need to have is there.

Does this system provide support when you need it?

No: There's never enough support when you need it.	1	2	3	4	5	6	7	8	9	Yes: All the support I need to have is there.

Do you feel in control when you use this system?

No: the software feels as if it controls me.	1	2	3	4	5	6	7	8	9	Yes: I can make the software do all I need it to do.

Do you think it's easy to get started with this system?

No: it gives you a very hard time at the beginning.	1	2	3	4	5	6	7	8	9	Yes: you can get into it right away.

10.4 Appendix D – Database Schema

stops_gda.shp (stops_id, Rte, Dir, Stid, Str_no, Street, X_street, Landmark, Tpid, Suburb, Postcode, Fare_secti, Met_zone, Latitude, Longitude, X, Y, Feature, Vertex, Stopgroup, Trnsfrnode, Tempstop, N5, Agd66lat, Agd66long, stop)

Field	**Description**
stops_id	Unique identifier for each tram stop in the network
Rte	Route number of tram
Dir	Direction of tram (I = inbound, O = outbound)
Stid	Stop number for this particular route (matches timetable and tram stop signs)
Str_no	Street number
Street	First street of intersection of stop
X_street	Second street of intersection of stop
Landmark	Landmark to identify stop
Suburb	Suburb of stop
Postcode	Postcode of stop
Fare_secti	Fare section indication
Met_zone	Zone of stop
Latitude	Latitude of stop (VicGrid)
Longitude	Longitude of stop (VicGrid)
X	Latitude of stop (WGS84)
Y	Longitude of stop (WGS84)
Stopgroup	Stopgroup identifier, used to group nearby stops
Trnsfrnode	Transfer node identifier
Tempstop	Temporary stop identifier
Agd66lat	Latitude of stop (AGD66)
Agd66long	Longitude of stop (AGD66)
stop	Stop number for WML display

EventTable (ID, rte, rteDir, stop, Event, EventStartTime, EventDuration, EventEndTime, Delay)

Field	Description
ID	Unique identifier for event
rte	Route number of tram affected by event
rteDir	Direction of tram route (I = inbound, O = outbound) affected by event
stop	Stop affected by event
Event	Event type (e.g. accident, traffic delay)
EventStartTime	Start time of event
EventDuration	Duration of event (minutes)
EventEndTime	End time of event (= EventStartTime + EventDuration)
Delay	Expected delay due to event

links_table (ID, fromnode, tonode, route, dir)

Links join two transfer nodes, for a particular route and direction.

Field	Description
ID	Unique identifier for link table entries
fromnode	Transfer node at which the link starts
tonode	Transfer node at which the link ends
route	Route of tram along link
dir	Direction of tram along link

stops (<u>ID</u>, stops_id, stop)

stops matches stops_id (unique identifier for stop number) to the stop number in the real world

Field	Description
ID	Unique identifier for stops table entries
stops_id	Unique identifier for stops
stop	Contains stops_gda.stid values

TransferNode (<u>ID</u>, tNode, stopID, stop, rte, rteDir)

TransferNode table contains the transfer nodes and associated details

Field	Description
ID	Unique identifier for TransferNode table entries
tNode	Transfer Node
stopID	Contains stops_gda.stops_id values
stop	Contains stops_gda.stid values
rte	Tram route
rteDir	Contains stops_gda.dir values

Traversals (ID, fromnode, tonode, route, dir, day)

Traversals is a dynamically populated table for each route request from the application. It contains all possible traversals based on the time of travel

Field	**Description**
ID	Unique identifier for Traversals table entries
fromnode	Starting point of link
tonode	End point of link
route	Tram route
dir	Direction of tram route
day	

routeXUschedule (ID, stop1, …, stopn) – *sequential integer increments for stop numbers for this route and direction*

Scheduled timetable for a particular route (X) in the U direction

routeXDschedule (ID, stopn, …, stop1) – *sequential integer decrements for stop numbers for this route and direction*

Scheduled timetable for a particular route (X) in the D direction

10.4.1 Relational Algebra

The derivation of several tables relied on extracting information from the spatial database tables. The following relational algebra statements describe how the tables were populated.

stops = $\pi_{\text{Stops\_id, stid}}$(stops_gda.dbf)

rows with blank stid assigned 0

TransferNode = $\pi_{\text{trnsfrnode, stops\_id, stid, rte, dir}}$(stops_gda.dbf)

only considering rows with trnsfernode > 0
rows with blank stid assigned 0

TransferNode = $\pi_{\text{trnsfrnode, stops\_id, stid, rte, dir}}(\sigma_{\text{trnsfrnode} > 0}$(stops_gda.dbf))

links_table = manually created by checking each transfer node for connecting nodes and recording the connecting routes and directions

traversals = dynamically created at run time based on links and tram schedules populated if a link exists between the two nodes and the timetable > the proposed travel time

EventTable = manually created to simulate real time vehicle data being added to the database

10.5 Appendix E – Research Website