Global Smart Spaces

The Smart Traveller Information System

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A dissertation submitted to the University of Dublin, in partial fulfilment of the requirements for the degree of Master of Science in Computer Science

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Declaration

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university.

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Summary

The essential character of a travel information system is a service which assists a traveller in choosing, refining, and then following the route of a pre-determined journey from a chosen starting point to a destination.

The Smart Traveller Information Service aims to provide users with a means of planning a journey through the Dublin metropolitan area, using multiple modes of transport. The project goal is to bridge the co-ordination gap between public and private modes of transportation by suggesting journey routes according to various traveller preferences.

The secondary goal is to demonstrate that spatial context can be exploited to provide a basis for offering pervasive information services to users. The proposed service aims to use a spatial programming model, in order to offer useful travel information services based on the data from this model.

The Smart Traveller Information Server (STIS) supports multi-modal journeys using up to five different modes of transportation. All the data supporting this service is taken from an existing spatially-enabled database, formatted and presented to the requesting user in the form of a detailed journey travel plan.

The STIS system was originally proposed to provide a stand-alone service taking user requests and returning responses over an XML interface. This project scope was later enlarged to encompass a presentation layer capable of displaying the route data visually. In addition the system provides a means of route refinement, both by waypoint location and transport type, and a device-independent journey plan capable of display on multiple devices.

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Tables and illustrative material

1 Introduction

"*Under his (Phileas Fogg's) arm might have been observed a red-bound copy of Bradshaw's Continental Rail and Steam Transport and General Guide, with its timetable showing the arrival and departure of steamers and railways*" – from ***'Around the World in 80 days'*** by Jules Verne (1872)

The origins of the travel information service can be traced back to the initial advancements in mass transit systems, first realised during the industrial revolution of the 19th century. Canal barges and steam-driven locomotives provided a cheap, reliable and affordable means hauling goods and passengers over relatively long distances. The steam-driven locomotive especially, opened up new opportunities of travel to the average person and ushered in the first commuter services.

The rapid expansion of those early mass transit systems created a new set of problems to be overcome. With the increasing complexity of the early railway infrastructures, a standard (universal) time had to be introduced, as well as a rigorous codification of train departure and arrival times.

Starting in the early 1840's, one George Bradshaw of Lancashire, England, began producing the first combined volume of railway timetables, including large-scale area maps, describing the times and movements on the new railway network in Britain[3]. This almanac of travel data was later expanded to include many more countries, and shortly before the outbreak of hostilities in 1914 it contained a reference guidebook to nearly every train service in mainland Europe, along with a companion hotel and travel guide.

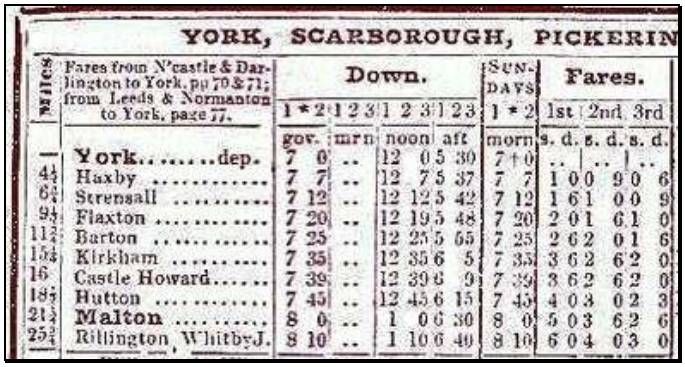

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Figure 1 - Bradshaw's Combined Train Timetable (excerpt) from 1850[3].

The drive for the codification and publication of railway travel information can be thought of as the precursor to nearly all of the travel services available today.

In parallel with to the expansion of the canals and railways, an effort to extend and improve the road network was initiated from the mid 1800's. Previous to this, most European road systems had been badly paved efforts following the contours of earlier pathways, cattle trails and Roman roads. Some of these Roman road networks, which reached their zenith in the 4th century A.D., were unsurpassed again until the early 20th century both in terms of reach and technology. After a lull in road building for the greater part of a thousand years, the main efforts to expand the assorted European road networks coincided with the various requirements of the industrial age. These were driven principally by the need to widely transport the goods produced by the industrial revolution, by war, and most importantly by the invention of the internal combustion engine in 1879.

In common with most modern European cities, Dublin possesses a street system inherited from various overlapping historical periods. The streets vary greatly, from the wide boulevards of the Georgian squares, to the cluttered medieval alleyways of Temple Bar and the narrow one-way streets of the north inner city. As a result of the relatively narrow roads, and winding streets, Dublin possesses its share of traffic problems, and often experiences traffic gridlock during the morning and evening rush hours. Dublin City Council has been using a traffic flow system called SCATS to direct the flow of traffic as best as possible, altering the cycle times of traffic lights to the time of day and current traffic conditions. However, even with this system in place,

and a dedicated traffic control office, the physical limitations of the Dublin road network continue to cause commuter headaches.

The principal mode of commuter travel remains the automobile, however there a number of complementary means of public transport available such as Dublin Bus, the Luas tram system, and the DART light rail network. By and large these networks are separated from the private road users by reserved lanes and tracks, however some Luas and Dublin Bus route do occasionally get delayed by traffic congestion along Dublin streets.

The goal of many commuters in Dublin is to *minimise the likely delay encountered whilst driving or using public transport in Dublin*. Typically most commuters stagger their journeys to travel outside of peak hours, or avoid well known traffic bottlenecks. In addition, commuters may access some existing information sources giving traffic and public transport updates, however at the present time these services are still rather limited in their scope.

This project is the logical progression arising from two distinct ideas, firstly that the road transport network in Dublin is becoming more constricted by the growing volume of daily commuters, and secondly that the increasing inter-connectedness of both public and private transportation modes is under-utilised by commuters currently when planning journeys. The impetus behind this project therefore, is to take existing information about Dublin transport networks, derive useful journey routes for travellers using the available data, and allow for the addition of new data streams at a later date.

1.1 Goal

The central idea behind Global Smart Spaces is to leverage an IT-rich environment in order to extract information about the context or the location of "services" available to a user within their immediate physical surroundings. This project, the Smart Traveller Information Service (STIS), is part of a larger research effort into Global Smart Spaces, and arises out of previous work done in the iTransIT project.

The goal of this project is to provide urban and sub-urban commuters in Dublin with up-to-date travel information, taken from a number of disparate legacy travel data sources, supporting a number of different modes of transport, from public bus services to trams, automobiles and cycling/walking. The output of this project is to be travel information, provided to the user, and taking the form of a journey itinerary using multiple modes of transport to comprise a single route.

In Dublin currently, the main modes of public transport, car, bus, metro (DART), train and tram (Luas) each have a web-site each dedicated to the provision of timetable information, route information, ticketing, etc. However, although the Irish national transportation company, Corás Iompair Eireann (CIE), manages Dublin Bus, Intercity coaches, Intercity trains and the DART metro, there is no single CIE web-service which permits users to plan a journey using all these modes of transport in the same route plan. For example a user wishing to travel from Heuston station to Donnybrook in Dublin (a journey of approximately 8km), must independently search the tram (Luas) timetables, the Dublin bus timetables, and in addition find the location of the Luas stop relative to the bus stop and the walking route between these two.

If a user is to truly benefit from the latent information available across many existing transport networks, the data must be retrieved in (near) real-time from many heterogeneous data sources, tabulated, and presented quickly and simply to a requesting user. In addition the requesting user must be able to refine the search parameters according to imprecise inputs, spatial coordinates or other travel preferences. The differences between the underlying transportation options should be presented to the user in as similar a fashion as possible, so as to encourage multi-mode journeys, and to guard against over-reliance on one or other form of transport information.

The long-term goal of providing this type of integrated travel planning service, would be to increase the number of commuters using public transport, reducing the number of single-occupant vehicles from the road network, decreasing the reliance on fossil fuels, improving government interest in the funding of public transportation and benefiting the overall environment.

1.2 Approach

Early Internet travel services were typically presented in a static fashion, similar to their paper-based counterparts, with perhaps a limited query interface. However as the popularity of the Internet grew, these travel services began providing dynamic content, for example, by offering users route maps, hyper-linked route timetables, multi-mode transport options and estimates on the expected journey time for a user-defined route.

In tandem with the ever increasing availability of user-searchable travel applications, the increased processing power and connectivity of wireless mobile devices has began to replace the typical urban/sub-urban traffic information sources, such as guidebooks, street-maps, and other paper-based travel information, with networked travel applications residing on personal computing devices such as mobile phones and PDA's.

In addition, with the high levels of Internet availability, especially in Ireland, there has been an equal focus on the provision of web-based travel information systems. Current web-based applications, some presented here in this document, have the capability to provide route guides (both textual and graphical) over the Irish road network, with some specifically tailored towards the Dublin metropolitan area.

For mobile devices, many static train, bus and metro timetables are available via SMS short-codes and WAP/CHTML. These services are being improved on steadily, allowing some GPS-equipped mobile devices to act as dynamic routing and mapping units, most notably installed in automobiles and other road vehicles.

The approach towards this project is to study the current state of the art in travel information services, applying this knowledge towards the design of a multi-modal travel planner for the Dublin metropolitan area. The software implementation will reflect the constraints and specifications outlined in section 3.1 of this document. The principal approach is to take the existing travel data (in a spatial model of Dublin's travel services), and construct a journey planning service which goes farther than the existing travel planning services available for Dublin.

1.2.1 Roadmap

Chapter 2 introduces the concept of a Smart Traveller Information Service, and presents an overview of the current state of the art in traffic information services, focussing on web-based mapping and routing services. In this chapter there is also a comparison of each traffic information services against the Smart Traveller Information Service (STIS) to be implemented for this project.

Chapter 3 is a description of the initial architecture design, an outline of the potential problems this architecture may have to overcome, and a description of the design decisions taken for the various logical components of the system.

Chapter 4 illustrates the issues involved implementing the Smart Traveller Information Service, the difficulties encountered, and how they were overcome.

Chapter 5 describes the means used to evaluate the software developed for this project, the results of these evaluations, and a discussion on how the system as a whole could be improved.

Chapter 6 is a summary of the main conclusions of this project, its implementation, design and performance. Included this chapter is a discussion of potential future work, which could build upon the work done in the project.

Chapter 7 is a bibliography, listing all the resources, both printed and electronic, touched upon during the project.

2 State of the Art

"The journey, not the arrival matters." – quote attributed to T.S. Elliot

There are a large number of, mostly web-based, routing and mapping applications available currently, allowing both mobile and web-based users to plan their journey online before setting out. Some more advanced mobile applications incorporate positioning, and real-time traffic information to give users the ability find routes dynamically, whilst travelling.

The main focus of this chapter is to evaluate the network-based journey planning services currently deployed on the Internet. In addition this section will compare and contrast these existing services with the proposed scope of Smart Traveller Information Service.

The majority of routing services deliver relatively static map, timetable, or route data for user-defined journeys through the road network mostly, with a heavy focus on vehicle traffic routing. Some vehicle routing services use dedicated in-vehicle routing and mapping units, e.g. GPS car kits, however most of these are not network connected, and provide, in essence, interactive route maps based on the vehicles current location.

Typically most currently available journey planning web services offer only an extremely limited routing service, in general based on a single transportation method. However there are a number of integrated transportation systems offering commuters multimodal journey plans using a variety of public transportation options. The impetus behind these multi-modal routing services tends to be where there is a centralised public transportation strategy for a city, a single state-owned transportation company, or where the transportation services have such large networks that users require assistance planning journeys. Most major European cities are beginning to make these types of integrated travel services available, as the burgeoning public transport infrastructure offers more choice to commuters and visitors travelling around a city.

2.1 Web-Based Mapping and Routing Service

2.1.1 Dublin City Live (Traffic Congestion Map)

This web-based service is provided by Dublin City Council, ostensibly to give commuters a graphical view of the road traffic congestion on Dublin city's streets. Dublin City Council themselves say on the web-site that the services aims "to deliver real-time traffic information to DCC website users"[4].

Figure 2 - DCC Travel Map

The road network is represented as a web of unnamed lines representing the main roads around the city centre, with place names for outlying districts, e.g. Phibsboro, Cabra, Rathmines etc.

The congestion levels of the roads are represented using four colours, green for light traffic, yellow and red for progressively heavier traffic and grey for no data. On the map are also some icons indicating parking facilities and traffic cameras. The traffic camera icons can be selected to show the current view of the traffic. However the images can often be quite out of date.

The web-site limits itself just to a dynamic traffic congestion display, there are no indications about the effect of congestion on public transport, nor are there any facilities for the web service to suggest alternative routes around congestion areas. The provision of public transportation is overlooked, and the web-site itself can take quite a while to load at peak times (evening rush hour).

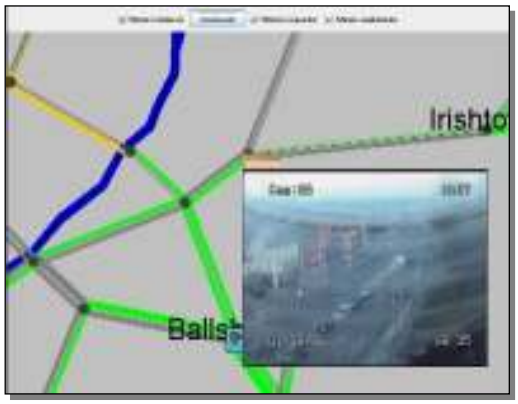

Figure 3 - DCC Traffic Camera View

The underlying XML data is accessible, so there is a possible security implication of having the "raw" traffic data available for public viewing.

In a somewhat related service, Dublin City Council also provides a broadcast service over FM radio, providing general traffic updates to users at peak times [5]. This service utilises the same traffic camera images which are available in the web-site, as well as providing radio listeners with a dial in number to leave traffic information.

2.1.1.1 Comparison with STIS

There are no direct points of comparison between Dublin City Council's web-site, and the proposed Smart Traveller Information Service. Firstly there is no routing of information provided to the user beyond the graphical map displayed on the initial page. In addition the congestion levels indicated in the map are only applicable to the road network, and do not deal specifically with any interference likely to bus lanes, metro (DART) or Luas services.

Description	***DCC web-site***	***Proposed for STIS***
Journey query interface	No	Yes
User-definable route search	No	Yes
Search parameter refinement	No	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	General map	Yes
Route text information	No	Yes
Road Traffic Congestion Levels	Real Time	Simulated
Public Transport Information	No	Yes

2.1.2 Dublin Transportation Office (Route Search)

Dublin Transportation Office (DTO) web-site provides a journey planner to help commuters in the Dublin greater metropolitan area [6]. The DTO organisation is dedicated to implementing the Irish government's Dublin Transport Initiative, and as such can be considered an organisation within the Department of Transport.

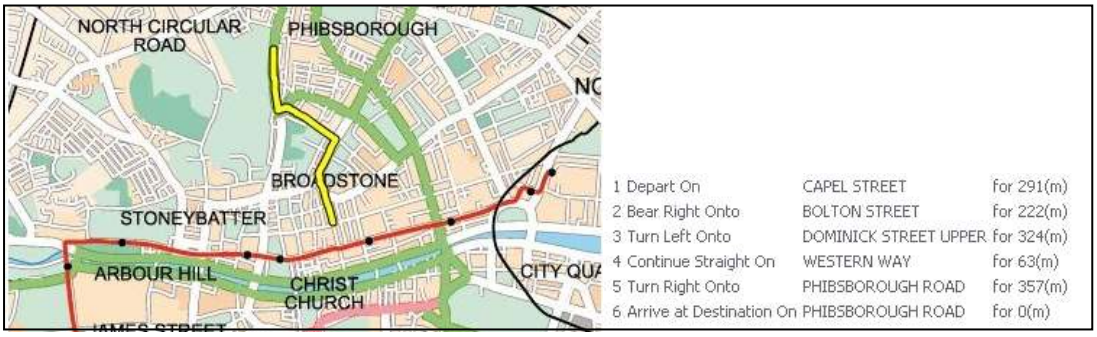

Figure 4 - DTO journey planner map and route

The DTO journey-planner provides a walking and cycling routing planner, allowing the user to input a start and an end point for the journey. The user input can be refined, as the system returns a list of address possibilities (if they exist) for both inputs. This selection process allows a user to quickly filter out undesired way-points, or correct mistakes. The search results returned give the user the route both as a textual description, and graphically with the route marked on a map.

The system is somewhat limited in that the journey route proposed by the system is limited to cycling or walking – there is no travel information regarding public transportation data into the route suggestions by the system (aside from some waypoint routing via DART stations). It is possible that drivers could use the service to plan routes across the city; however the web-site does not provide any traffic congestion information.

2.1.2.1 Comparison with STIS

The DTO journey planner provides a simplistic but useful routing and mapping interface. The web service limits the user to one of three modes of travel – walking, cycling or automobile. Someone using the service can enter a search parameter, and

be provided with a number of options to refine the search parameter. For example, typing "LEESON" as a search parameter yields a number of options including LEESON STREET, LEESON PLACE, etc. This feature is very useful in allowing a commuter to refine vague search parameters into more definite search items.

Description	***DTO web-site***	***Proposed for STIS***
Journey query interface	Yes	Yes
User-definable route search	Yes	Yes
Search parameter refinement	Yes	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	General map	Yes
Route text information	Yes	Yes
Road Traffic Congestion Levels	No	Simulated
Public Transport Information	Limited	Yes

2.1.3 Transport for London (Integrated Travel Planner)

The Transport for London (TfL) web-service appears to be a more expansive, and elaborate version of the DTO travel planner, focusing on commuter journeys in London using a number of means of public transport [7]. The public transportation options in a major urban centre such as London are varied and well supported, with a well developed infrastructure and good integration between different modes of transport.

The principal public transportation modes under the direction of the TFL are

- London Busses
- London Underground
- River Transportation Services (River Ferries)
- Light Railway Services

In addition to the public transportation services, the TFL organisation manages the London congestion charging scheme, whereby road users within the city limits are charged a fixed daily rate, which at time of writing is £5 GBP. The main focus of the TfL web-site however is the provision of a commuter journey planning tool, which integrates all the public transport options into a single relatively seamless travel plan.

Figure 5 - TfL Journey Planner

A user first enters a search parameter, typically a street or place name, and is presented with a number of options to further refine the search. For example, a search giving the "British Museum" as a place of interest returns a number of possible candidates, such as the "British Postal Museum". The facility is very useful if there are a number of possible candidates for either the start or destination, or, if the user has an inexact

idea of their name or address. It could also be argued that a comprehensive listing of all the available options could also lead to some confusion when selecting route waypoints.

Once a journey origin and destination are fixed upon, the user is presented with a number of options based on the type of travel connections possible to complete the journey - with various times, distances and travel mode differences outlined.

2.1.3.1 Comparison with STIS

Of the various web-based journey planners available, the TfL service is perhaps the most well implemented, and user friendly. The scale of the public transportation in London is enviable, and the service does an especially good job of integrating various transportation modes into a single user-defined journey.

There are however a number of drawbacks to the system, including some omissions which are included in the proposed STIS system. Chiefly among the limitations is the requirement to "know" your current location, journey origin and destination before you begin a search. There is no support for spatial queries, and the graphical map returned to the user is more a logical representation than being geographically accurate.

Description	***TfL web-site***	***Proposed for STIS***
Journey query interface	Yes	Yes
User-definable route search	Yes	Yes
Search parameter refinement	Yes	Yes
Spatial search support	No	Yes
Dynamic Routing support	Yes	Yes
Route map information	Logical map	Yes
Route text information	Yes	Yes
Road Traffic Congestion Levels	Some	Simulated
Public Transport Information	Yes	Yes

2.1.4 AA Roadwatch – Route Planning Service

The Irish Automobile Association (AA) provides a limited road route-planning service, which allows users to enter a start and destination place-name, and be provided with a textual description of the route of their journey [8]. The service is tailored predominantly towards vehicle commuters, and the routing parameters provided give drivers succinct information to get to their destination. The routing parameters list the road identifier, e.g. N7, the cumulative distance in miles, and turning/junction directions. The information returned from the routing service suggests the service is more tailored towards inter-city journey planning along national roads than routing within an urban environment.

Figure 6 - A composite of two images from the AA Route Finder Service [8].

The AA routing service does provide users with the ability to refine their search, according to a list of street and place names. The fact that the AA routing system encompasses the entire Irish road network, or so it seems, has a drawback in that refinement options can often list very different areas in the country.

2.1.4.1 Comparison with STIS

The AA journey planner offers a similar, but much more basic, service than what is proposed for the STIS system. The principal area of similarity is the provision of a textual description of the journey from start to destination. There is, more than likely, a detailed spatial database behind the AA routing service, however there is no mapping or graphical component to the service. This lack of a route map is possibly due to either complexity in implementation or, more likely, high costs associated with providing graphical maps to the public.

Description	***AA web-site***	***Proposed for STIS***
Journey query interface	Yes	Yes
User-definable route search	Limited	Yes
Search parameter refinement	Yes	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	No	Yes
Route text information	Yes	Yes
Road Traffic Congestion Levels	No	Simulated
Public Transport Information	No	Yes

2.1.5 Washington State Commuter Map (Traffic Congestion Map)

The Washington State Department of Transport provides a traffic congestion map via its web-site. Being based in the united states, the target consumers for this service are almost entirely automobile-based commuters using the state's highway system [9].

A user can view a graphical map representing the traffic density on the main motorways, as well as textual information on planned roadworks, and expected delays depending on the time of day and traffic density.

In addition to labelling the principal towns and motorways in the area, there are placed throughout the state, a number of publicly accessible traffic cameras which are focused on major roads and intersections.

There is no functionality available on the web-site for routing around traffic bottlenecks, but at least a user can get a reasonably good idea of traffic conditions both with the map information, the text description, and the traffic camera images.

2.1.5.1 Comparison with STIS

Similarly with the Dublin City Council traffic map, there are few points of comparison between this service and the STIS system. The main areas of similarity are the provision of traffic congestion information, and a textual summary of the likely journey duration and distances for a user-defined search.

Description	***Present in DTO web-site***	***Proposed for STIS***
Journey query interface	Limited	Yes
User-definable route search	No	Yes
Search parameter refinement	No	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	Graphical map	Yes
Route text information	Limited	Yes
Road Traffic Congestion Levels	Yes – Highways	Simulated
Public Transport Information	Very Limited	Yes

2.1.6 Google Maps (Route and Map Search)

The Google Maps service was launched in 2005, and initially provided map information restricted to the continental united states. Shortly thereafter map information was made available covering Ireland and the UK, providing detailed urban street maps and satellite images [10].

This type of mapping service is not unique, in that there were online mapping and routing Internet applications before it appeared, but it is perhaps one of the best executed web services of its kind at the moment, second only perhaps to the Map 24 service [11].

Figure 7 - Google Maps Example

The Google Maps interface uses Java Ajax technology to provide an interactive interface to users, allowing route searches, as well as very detailed street-maps and satellite imagery.

Routing information is provided both in a graphical map format, as well as text describing the directions for the journey.

The principal disadvantages of the Google Maps web service is the complete exclusion of any public transportation routing options. In addition there seems to be no address lookup functionality for Dublin (or other Irish) street addresses. A user searching for even a relatively well known address such as "College Green, Dublin, Ireland" will not be successful with the current incarnation of the Google Maps service, as of September 2006.

There are plans to expand the service to include some public transportation options when responding to a route query. However Google state that this service, when it is launched, will be limited to the "Portland, Oregon metro area, but we plan to expand to cities throughout the United States and around the world" [12].

At the time of writing Google are planning have launched a beta-version of their web service specifically designed for mobile devices. This service optimises the Google Maps functionality and graphics for display on more restrictive mobile screens, but provides the same overall type of service and content [13].

2.1.6.1 Comparison with STIS

Google Maps is primarily a source of map information, with routing and public transportation very much a secondary consideration. There are limited areas of overlap between the STIS service and the Google Map offering. Outside of the united

states, the recognition of place-names is very poor, and it appears there is no European GIS database offering address validation or lookup.

Description	*Google Maps web-site*	*Proposed for STIS*
Journey query interface	Limited	Yes
User-definable route search	No	Yes
Search parameter refinement	No	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	Graphical map	Yes
Route text information	Limited	Yes
Road Traffic Congestion Levels	Yes – Highways	Simulated
Public Transport Information	Very Limited	Yes

2.1.7 Map 24 Service (Route and Map Search)

The Map 24 web-site hosts a route search and mapping application [11], for both the US and a number of European countries, much like Google Maps. The interface provides a slightly better user experience than Google Maps, mostly by providing users with a toolbar giving scaling, rotation and zoom options, as well as novel features such as a ruler to measure distance (overlaid) on a map, and multiple distance waypoints to trace non-linear routes.

Figure 8 - Map24 route showing journey from Capel St. to the Phibsboro Road in Dublin[11]

2.1.7.1 Comparison with STIS

The Map24 service is an improvement on the Google Maps web-service, and contains a reasonably well executed map interface, and routing service, and detailed content. Unlike its Google counterpart, Map24 has a well furnished place-name database, covering the Dublin metropolitan area. It does not however offer the same satellite imagery as the Google Maps web-service.

The site graphics, especially the graphical description of the route, was an inspiration for the design of the web-front end in the STIS service. Since the STIS service is not predominantly concerned with presentation, but journey planning, it was felt much work could be done in a similar vain to Map24 interface with respect to the STIS web-front end.

Similarly with the majority of web-based routing applications, there is no consideration for public transport services when performing route searches. This restriction contrasts with the goal of the STIS system of integrating public and private transport mechanisms into a single journey plan.

Description	***Map24 web-site***	***Proposed for STIS***
Journey query interface	Yes	Yes
User-definable route search	Yes	Yes
Search parameter refinement	Limited	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	Graphical map	Yes
Route text information	Yes	Yes
Road Traffic Congestion Levels	No	Simulated
Public Transport Information	No	Yes

2.2 Web-based Public Transportation Information

2.2.1 Dublin Bus (Timetable and Route Search)

The Dublin Bus company [1] operates under the umbrella of the CIE group of companies [14], which are state owned transport companies providing much of the national bus and rail services for the country. Bus Eireann and Irish Rail also form part of CIE, and in a sense each of these public transport services can be seen as a different operating arm of the same company.

Figure 9 - Dublin Bus Route Search

Dublin Bus operates many services in and around Dublin City, as well as some services to more outlying areas (for example Blessington in Wicklow). Generally speaking however, Dublin Bus routes are largely confined to the Dublin metropolitan area, with Bus Eireann operating inter-city services across the country.

As with many urban bus services elsewhere, Dublin Bus assigns each of its routes a unique number/letter combination, which may not be immediately understood by tourists and other visitors to the city.

Figure 10 - Dublin Bus Stops (Left) and Route Numbers on Dublin Bus Services (Right)

This route number can be found printed on timetables at each bus stop, but unless a commuter is acquainted with the route number in advance, there is no information to suggest where a particular bus will stop. This requires an uncertain commuter to find the route number by other means, such as the internet, at a particular bus stop, or by enquiring elsewhere.

The Dublin Bus web-site provides a very limited search function (see Figure 9) which will provide bus stop and timetable information for a particular route, or a particular place name.

Figure 11 - Dublin City Centre Bus Stops [1]

In addition, the web-site provides a map (pictured on the left) showing the position of particular bus stops in the city centre, again listing each stop according it's the route number.

The routes themselves are not represented graphically, and the information provided about bus stops along the route is very minimal, listing a street-name or general area typically. This has the effect of leaving first time commuters unsure about the likely direction a particular route will take, or what intermediate stops they may encounter along the route.

2.2.1.1 Comparison with STIS

The Dublin Bus web-service is not much advanced from a digitised form of their paper-based timetable information. The location of bus-stops outside the city centre is not immediately available, nor is there any location information about areas not directly on a bus route.

Description	***Dublin bus web-site***	***Proposed for STIS***
Journey query interface	Yes	Yes
User-definable route search	Limited	Yes
Search parameter refinement	No	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	Textual/Limited Map	Yes
Route text information	Limited	Yes
Road Traffic Congestion Levels	No	Simulated
Public Transport Information	Some	Yes

2.2.2 Dublin Area Rapid Transit (DART)

The Dublin Area Rapid Transit (DART) system was installed in the early 1980's and skirts Dublin bay in a wide arc, from Howth in the north to Bray and Greystones in the south. Currently the DART network provides public transport to 90,000 commuters daily, and runs from 6am until midnight seven days a week.

The DART system is integrated with the Irish rail network, and uses the same gauge rail lines as Intercity trains. The DART system connects to the rest of the Irish railway grid at a number of key points, such as Connolly Station. At the time of writing there are no DART services connecting to Heuston Station, however there are plans to connect Heuston with the DART network by building a tunnel under the city starting from the IFSC, with work beginning in 2009 and scheduled to be complete in 2015. Rail connections to the south and west of Ireland are provided via Heuston station, and while there is a Luas stop, a DART connection would greatly ease the traffic congestion on the city's streets.

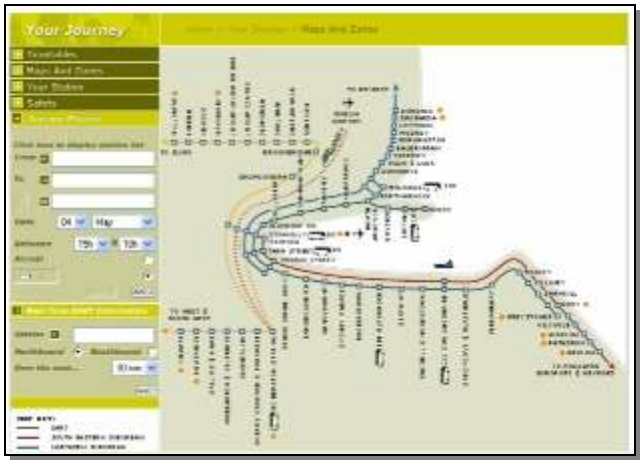

Figure 12 - DART Journey Planner [15]

The information available on the DART website, http://www.dart.ie, provides mostly static timetables, as well as information about ongoing disruptions, scheduled maintenance work, and ticket information. As was the authors experience of five years commuting to work on the DART, most disruptions to the service are neither expected ahead of time, nor quickly posted on the DART web-site. Chief among the disruptions occasionally experienced by commuters are vehicles hitting level-crossings and unscheduled industrial action by employees.

The search functionality incorporated into the DART web-site is linked with other rail services, and provides requesting users with a broad range of travel options, timetables, and details of Inter-City trains, Light Rail services and the DART. The web-site allows users to request a "multi-modal" journey, in the sense that both DART and regular train services can be queried and added to a single journey itinerary.

CIE provides a limited inter-working facility with Dublin's Luas network, in that travellers can purchase a combined Luas/Train ticket, however timetable information is not meshed for both services (possibly due to the difference in frequency of rail and Luas services).

There is also a combined DART/coach service to Dublin Airport, which again provides users with an all-in-one ticket to cover the cost of a DART journey to the Howth junction stop, with a coach transfer to Dublin airport. The information about

this special “AirDART” service can be found on the main web-page, but the frequency of service is not made clear for the coach transfer.

As the DART network is perhaps one of the more reliable (in terms of adherence to published timetables) it lends itself more towards web-applications targeting mobile subscribers. At the moment there is a service available using SMS short codes to retrieve timetable information for any DART station, and provide the next 5 outbound trains from that station.

The dynamic information, giving commuters news about delays in the DART service are available within DART stations on electronic signs, however the same service is not available over the Internet.

2.2.2.1 Comparison with STIS

The DART system does provide a better service than it’s counterparts in the CIE group of companies, in that it’s web-site features an interactive map giving the DART stations relative to the map of the Dublin metropolitan area.

Timetable information is available, and there is a good linkage with Intercity rail services, and some information about linkage with some Dublin bus and other coach services.

Description	***DART web-site***	***Proposed for STIS***
Journey query interface	Yes	Yes
User-definable route search	Limited	Yes
Search parameter refinement	No	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	Limited	Yes
Route text information	No	Yes
Road Traffic Congestion Levels	No	Simulated
Public Transport Information	No	Yes

2.2.3 Luas (Timetable and Route Search)

The Luas tram system is a light urban railway/tramway service in Dublin which began operating in 2004 [16]. The name "Luas" is derived from the Irish Gaelic adjectival word meaning "fast" or "speed", for example "ag dul thart ar luas", is the phrase "to pass at speed".

Previously there had been an extensive tramway system in Dublin up until the 1950's, however the thinking in urban planning at the time was more focussed on automobiles as the future transportation trend, and the tramways were paved over for road traffic.

Figure 13 - Luas web-site

The Luas system operates two tram lines, the red line, from Tallaght into the city centre, and the green line, from Leopardstown into St. Stephen's green. There are approximately 23 stops on the red line, and 13 on the green line. Travel times, and the frequency of service can vary somewhat but the typical travel time from one end of the line to the other is approximately 30-40 minutes, with a tram leaving approximately every 5 minutes at peak times.

There is some limited information available from the Luas web-site (www.luas.ie), providing details on routes, timetables and ticketing details. The Luas timetable information is somewhat vague, giving only frequencies of the service (measured in minutes), rather than any particular fixed timetable. Perhaps, since the frequency of service is comparatively large, and the journey time is small compared to train services, the lack of a strict timetable is not a great issue for commuters.

Located at each Luas stop (both inbound and outbound platforms) is an electronic board showing the estimated arrival time of the next tram and its ultimate destination. The presence of these boards at the Luas stops, and the regularity of the service (typically a tram arrives every 10-15 minutes), somewhat negates the need for commuters to consult a timetable to prior to commencing their journey.

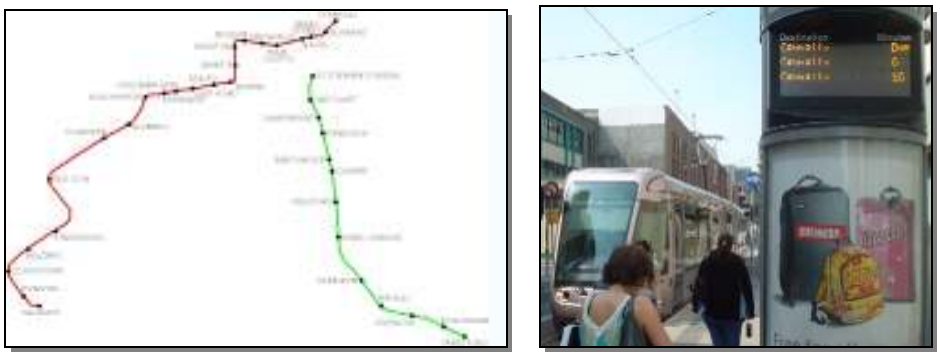

Figure 14 - Luas routes (Left) and a typical Luas Stop with information board (Right)

There is only a partial link up with other public transport services from the Luas mass transit system. At best a commuter may purchase a Luas ticket in addition to their train ticket, however there is no web-service available from the Luas home-page offering any multi-modal journey planning. The only extra information available on the Luas web-site is restricted to some web links to other travel operator sites, such as Dublin Bus, CIE and various national coach companies.

2.2.3.1 Comparison with STIS

Similar to the Dublin Bus web-site, the Luas web page seems to be focussed on providing an Internet version of the static timetable information for the service. The timetables provided are not particularly convenient, in that there are only frequencies of service published.

There is very limited information about how a traveller would find there way from an outlying Luas stop (or even a city centre one) to their final destination. In summary, the Luas web-site does not provide any further directional or routing information for its user's once they leave the Luas Stop.

The STIS system will incorporate both Luas lines, and will provide interlinking route data which extends beyond the Luas stop to the user's final destination.

Description	*Luas web-site*	*Proposed for STIS*
Journey query interface	Limited	Yes
User-definable route search	No	Yes
Search parameter refinement	No	Yes
Spatial search support	No	Yes
Dynamic Routing support	No	Yes
Route map information	Static route map	Yes
Route text information	Limited	Yes
Road Traffic Congestion Levels	No	Simulated
Public Transport Information	No	Yes

2.3 Comparison with existing travel systems

The travel systems presented previous in this section fall into roughly three categories,

- Map based web-services with routing functionality
- Real-time Traffic congestion web-services
- Public transport timetable and routing web-services

The closest web-services currently available to the proposed STIS project are the DTO mapping and routing application, followed by the Transport for London service, and then jointly by the Map 24 and Google Maps web-services. However, the STIS proposal will offer more functionality than a combination of these currently available web-based applications.

The majority of the travel planner applications are tailored towards web-based users, with a very limited provision for mobile subscribers using legacy terminals. Indeed, the majority of travel planner applications are inherently unsuitable for mobile devices, since most use client-side scripting, detailed graphics or other functions which do not translate well to the mobile domain. The critical areas of difference between the STIS proposal, and the current state of the art can be summarised as follows.

1. Routing functionality will incorporate routes across **different** individual public transport services, providing a single query interface, and a "holistic" journey plan incorporating individual sub-journeys.

2. The STIS system will accept inputs based on undefined, inexact search criteria. Unlike most traditional systems the physical location of a user can be provided as a search parameter, not merely a text input, but the co-ordinates of a user in a specific geographic format (e.g. OSI, WGS-84 etc.).

3. The STIS system will mix public transport travel information with private commuter (automobile) routing. The STIS system will be theoretically capable of handling input from Dublin Corporation's traffic congestion server (SCATS system), as well as other inputs from legacy travel data sources.

4. Timetable and route information from the underlying travel data sources will be parsed, and the information will be tailored relevant to a particular (single) journey.

5. The STIS system XML output can be tailored according to the display parameters of the target device. Hence the level of detail can be changed depending on what is required by the user.

Another difference, but not a crucial one, is that the STIS system will provide an XML interface, allowing the visualisation of the travel data (presentation layer) to take any form required. This feature will allow the STIS system to support any number of travel services, be they web-based services using web-browsers, or bespoke J2ME applications residing on mobile phones and PDA's.

3 Architecture Design

"Good puzzle would be cross Dublin without passing a pub" – James Joyce (Ulysses)

The early architecture design was begun in December 2005 when the project proposal was finalised. This proposal called for the development of a Smart Traveller Information System (STIS) capable of responding to user requests (originating in a separate presentation layer), with multi-modal journey plans encompassing the Dublin metropolitan area. Initially the presentation layer was outside the scope of the project, with the focus of the project was solely on determining the appropriate route, over multiple modes of travel, which would satisfy a given request.

There are a large number of available public mass transit systems, ranging from airliners and private cars, to public busses, cyclists and pedestrian routes. The types of public mass transit systems considered for this project were the Dublin Bus network (or part of), the Luas tram network and the Dublin road network as used by vehicles, cyclists and pedestrians. The DART [15] rail network was not included in the scope of this project, with the focus being mainly on the transportation methods which use (to some degree) the road network in Dublin, and which were already existent in the spatial database.

The decision to incorporate only these modes of travel, and not other, was primarily due to the fact large amounts of data already existed in these areas to provide a basis for implementing the system. Including extra modes of transportation can be done reasonably easily, provided the "raw" data is first available. In addition, there was earlier substantial work done in the area, specifically within the iTransIT project. The iTransIT project is a collective project between Trinity College Dublin, and Dublin Corporation, looking at various technologies and transport schemes affecting the city.

The Smart Traveller Information System was therefore borne out of the work done in the iTransIT project, especially earlier research work done with indexing and storing spatial objects [17], and the travel data already available from this previous work.

The system architecture for the newly designated Smart Traveller Information System, was initially designed on an informal basis. Later improvements and modifications to the design were added in an incremental fashion, which refined the overall design, and improved the overall implementation of the final system. The methodology applied to the initial design, was to iterative over the initial design, refining and testing the design assumptions until a final system implementation was produced. This process had the benefit of being quick to incorporate improvements in the design, whilst removing implementation obstacles.

Initially, taking the project proposal as a starting point, there were a number of 'open questions' left to complete before the final system architecture design could proceed. These uncertainties included:

1. *How to implement the interfaces to the user layer on one side, and the travel data sources on the other.*
2. *Whether to provide the interface in a bespoke manner, or using a common technology.*
3. *What would be the best way to construct a journey request, and a journey response, so it could be understood by the user/presentation layer.*
4. *The appropriate way to represent (internally) the public transport networks.*
5. *How to calculate a multi-modal route through this model of the transport networks.*

This chapter deals with the design choices faced during the early stages of the project, and the reasoning behind the important decisions.

3.1 System Requirements

The requirements the STIS system was obliged to fulfil, were worked out at a high level, in the early stages of the project. The amendments made to the initial system requirements were due to a combination of the original project proposal, the previous work done in the area, and from a number of project meetings with the project supervisor, Dr. René Meier.

At a high level, the system was described as a "service enabling travellers to plan journeys across Dublin involving multiple modes of transportation" [18]. This implication was that the user would somehow interact with the system (directly or indirectly), providing some journey parameters, and receive a reasonable, coherent response, which contains journey information. The interaction between user and service must allow for the refinement of various travel options, and a mechanism to present completed journey plans back to the requesting user.

This type of system, which was to act as a journey planner and routing service, must respond to the requesting user in an understandable (common) format, in addition to making sense of the user's inputs and calculating the journey route. The presentation of the journey information to the end user was the subject of a related MSc. dissertation project [19], however due to technical difficulties, this project was not implemented in full, and consequently a "presentation-layer" was added, as a requirement, for the Smart Traveller Information Service.

The system was not required to be a publicly accessible, nor be industrialised in any sense, but would server as more of a demonstration platform which could be used as a visualisation tool, and proof of concept by the travel data model in iTransIT. There was a requirement that the system should be capable of handling multiple clients, with a maximum of several (i.e. < 10) concurrent users.

Since the system was to be deployed on a 1.6GHz Dell laptop with 512 MB of memory, the STIS software was designed to be relatively efficient in the usage of system resources, and provide a reasonable response time to user requests, similar to existing web-services. The system was required to dynamically calculate all travel plans, thus excluding any pre-compilation of the information in the travel data sources.

The project proposal did not stipulate any technologies to be used within the project, with the single exception of using the existing spatial programming model to access the spatial objects representing roads, bus routes and Luas information. A design choice was taken to develop as much of the system as possible using the Java programming language and related technologies. This was done for a number of

reasons which are outlined in more detail in chapter 4, but in essence Java lends itself more towards rapidly developing web-services some other technologies.

3.2 Initial Architecture

The initial system architecture design was inspired by an early high-level project architecture diagram (see Figure 15). Fundamentally, the Smart Traveller Information Service (STIS) was to act as a middleware layer, residing between the requesting user's mobile device or web-browser on one side, and the travel data sources containing the spatial data on the other. In addition to the role as a middleware layer, the STIS system could be conceived of as a web-based journey planning service in it's own right, similar in functionality to the limited offering from the Dublin Transportation Office [6].

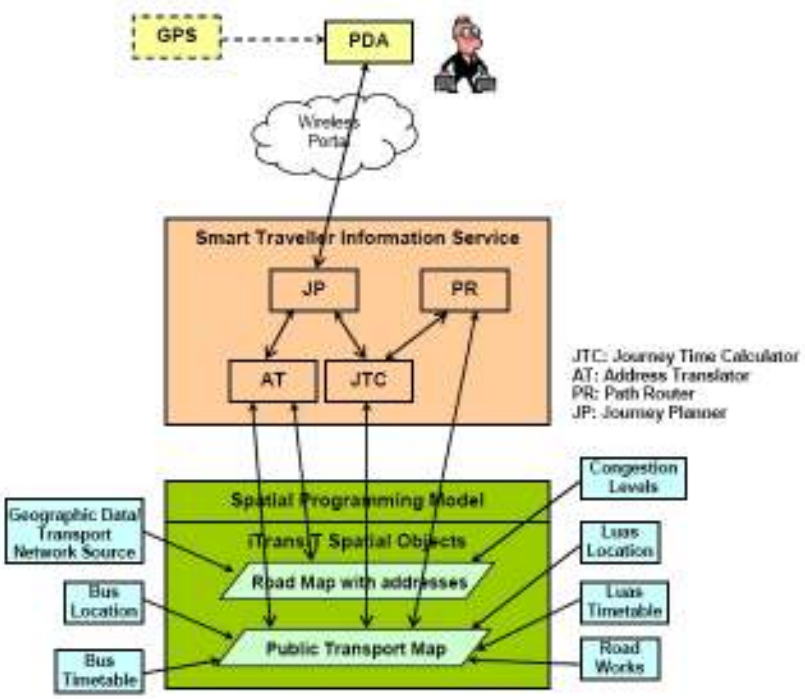

Figure 15 – Early High Level Architecture Diagram

The system receives user requests over a well-known interface, processes the request, retrieves information from the underlying data sources, encodes a response and sends the route back to the requesting user. The communication between the STIS middleware, and the presentation layer (end user) was designed to use an XML interface, for a number of reasons specified later in this chapter.

The interface to the spatial and transport data was designed to utilise as much of the existing spatial API's as possible.

There are a number of areas of common functionality described in the high-level system architecture, such as the address translator, path router, journey time calculator and journey planner. The idea was to separate as much as possible the handling of the user's request from the underlying data sources, and the calculation of the journey route.

The presentation of the STIS output to the requesting user was originally outside the scope of the project, however in the early stages of the design it became apparent that some rudimentary presentation layer was needed. As a result the amount of time available to work on the STIS system was reduced by the added requirements. Overall the time spent working on the presentation layer/applications compared to the time spent working on the STIS service proper, was in the ratio of approximately 40:60.

3.3 System Design

The STIS system was designed to act as a middleware platform, residing between the presentation layer (applications) and the travel data sources (spatial database). The responsibility of the STIS system would be to convert the user's input into a journey request, retrieve the relevant information from the travel data sources, calculate the journey, and present the result back to the requesting user.

The system design called for two main interfaces, a client-facing interface which would respond to user requests, and a database facing interface, where it was hoped the STIS system could use the existing Spatial API implementation to retrieve information from the database.

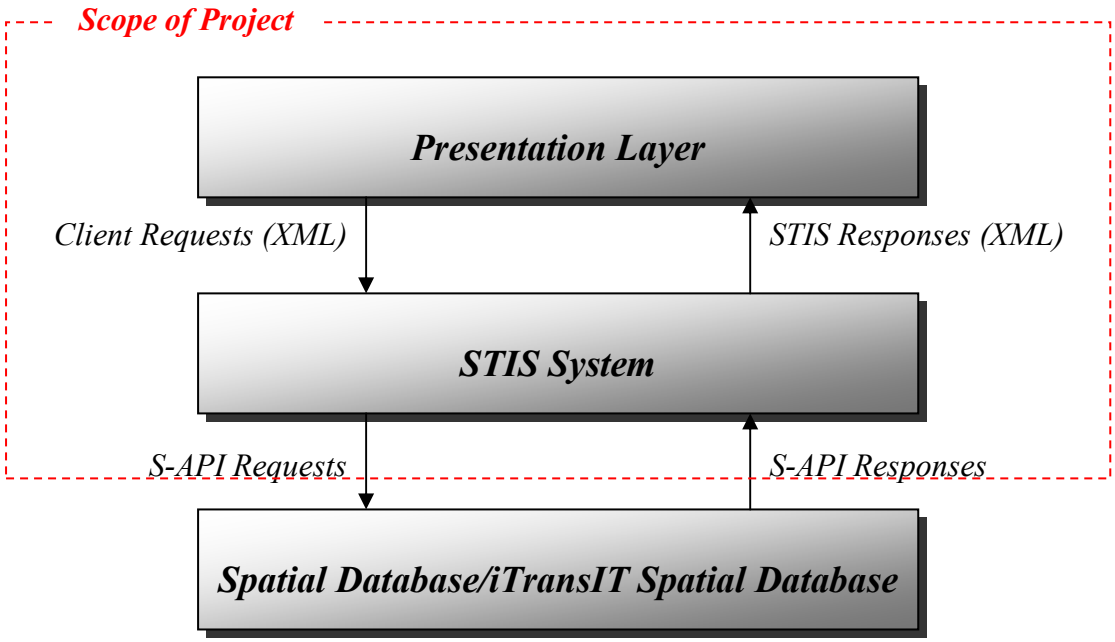

Figure 16 – High-Level View Of The Project Design

The spatial database, which formed the corner stone of the STIS project, was already existent thanks to previous work in a related project, as was the Spatial API (S-API) which provided an interface to this database. The work required to implement the STIS system was helped considerable by the fact that many of these relevant pieces of the design were already in place before the project was begun.

3.3.1 Class Diagram

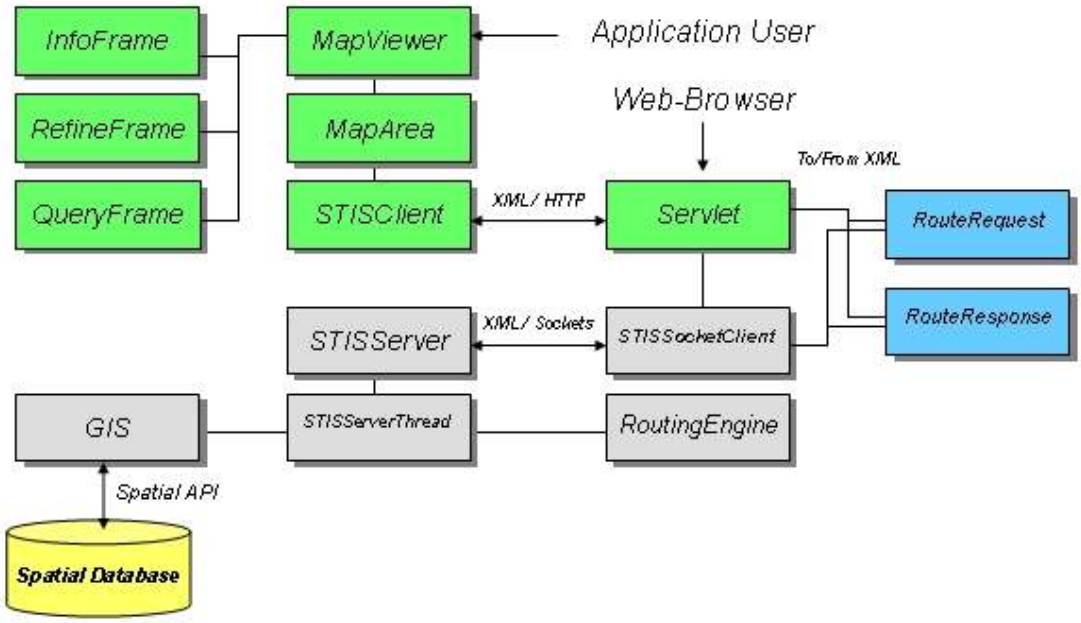

Figure 17 - STIS Class Diagram

The STIS architecture is comprised of a number of distinct logical blocks, each with a clear-cut focus and set of responsibilities. The system as a whole consists of four such logical elements,

1. *User Interfaces which facilitate the display of journey information as well as allowing route requests to be constructed and refined (Presentation Layer).*
2. *Communications functionality, both internally and externally (Communications Layer).*
3. *Journey planning and spatial data caching functionality (Service Layer).*
4. *Data encapsulation and formatting functions.*

3.3.2 Presentation Layer

The presentation layer was originally conceived as a typical GUI interface providing means to access the underlying STIS system. To support this presentation layer, the STIS system was required to provide a user front-end, in order to allow user inputs,

and to graphically interpret the spatial information/journey routes produced by the STIS service.

The original project proposal for the Smart Traveller Information Service (STIS), called for the provision of a stand-alone journey planning and routing service, communicating with the outside world over a well-known interface in an agreed format. This view of the system was changed in the early stages of the project due to technical difficulties with another dependent project. Consequently a visualisation mechanism, or presentation layer, was required for the STIS system, both to construct journey plan requests, and display the STIS output in a graphical form. For verification purposes alone, a graphical means of displaying a route improves error detection, and reduces implementation time considerably.

There was no firm design requirement for the presentation layer, other than it should be capable of displaying the output of the STIS service graphically, overlaid on a map of Dublin. This freedom in the early design process resulted in a presentation layer divided into two distinct user interfaces, a stand-alone GUI application (*Map Viewer*) and a web service (*STIS Servlet*). The Map Viewer application was developed in response to the requirement to have a tool available during the implementation phase which could be used to display nascent STIS system outputs. This tool developed into the Map Viewer application, and was designed to have more functionality than the more limited web-based user interface. This STIS servlet web interface was designed as a proof-of-concept example of how a web-service which could use the STIS routing functionality.

With this in mind, the ***STIS servlet*** design goals were to allow users to remotely access the STIS journey planning service from a web-browser, connect to the STIS system over HTTP, and display the resulting route graphically within the web-browser. As a proof of concept web-service, the STIS Servlet was not intended to offer the same level of routing functionality, as other existing web-services, e.g. Google Maps.

The web-service was designed to offer users the choice of inputting a number of relevant journey parameters, such as the journey start/destination, waypoints along the

route, as well as a preferred means of travel. These initial inputs were intended to be first refined, and a choice of options presented back to the user. Once the final journey options were selected the servlet was expected to display the journey response both graphically and textually in the user's web-browser.

As a later addition during the design process, the STIS Server was also re-modelled to also provide an application-level communications end-point, facilitating HTTP communication between remote applications an the STIS service layer.

In contrast to the STIS servlet, the ***Map Viewer*** application was designed primarily as a development tool, to assist in the testing and verification of the STIS journey planner. This application was expanded during the design process, eventually becoming a stand-alone journey-planning application in its own right. The Map Viewer, as the name suggests, was planned to display the various spatial elements, such as junctions, Bus-stops and Luas-stops, overlaid on a street-map of Dublin. This composite map could be browsed by the user, and a journey request could be constructed, refined, and eventually displayed in the application.

3.3.3 Communications Layer

In order to provide a viable, timely service to requesting applications in the *Presentation Layer*, a communications layer was vital to convey requests for spatial information from the user to the STIS service layer, and reply with appropriate data back to the requesting user/application. A number of classes were developed to cope with the communications requirements placed on the system, such as the user-facing ***STIS Client*** and the server-side ***STIS Servlet*** and ***STIS Socket Client***.

The role of the ***STIS Client*** was to provide applications in the presentation layer a simple means of sending data to the STIS Server, retrieving responses and passing this information back to the requesting application in an agreed form. The STIS Client responsibilities included setting up a HTTP connection to the STIS Servlet, formatting application requests into XML, sending the requests over the HTTP link, parsing the XML responses, and passing the parsed information back to the application. The STIS Client could be thought of as a remote "stub" of the *STIS Servlet* class, in that it

removes the complexity of communication from the application/presentation layer, supporting data is formatted correctly both in sending it to the service layer, and changing its format, where appropriate on return.

The ***STIS Servlet*** class provided the HTTP communication endpoint on the server side. This class, which used the standard javax.servlet API's, was chiefly concerned with HTTP communications on the client-side, and TCP/IP socket communications on the server-side. The STIS Servlet was designed as a web-front end, bridging the different communications modes between client and server.

The ***STIS Socket Client*** provided the socket communications functionality to the STIS servlet, in a similar form to the STIS Client class. The role of the STIS Socket Client was to open a socket connection between the servlet and the STIS Server. Data was then read from the HTTP request, and sent over the socket connection to the STIS Server. Unlike the STIS Client, the STIS Socket Client would not be required to perform any parsing or re-formatting actions on the data, since the body of the HTTP request was already an XML string. This XML could be sent directly to the STIS Server without modification. Likewise any responses send over the socket channel from the STIS server would also be encoded as XML strings, and could be directly fed back to the STIS Client over the HTTP connection.

3.3.3.1 HTTP Communications

The initial design called for a communications interface, preferably using a well-established communications mechanism, capable of efficient operation and low-latency. A decision was made early in the project to provide all remote communications to and from the STIS server front end using HTTP where possible, with a TCP socket for the server back end communication. This choice was due mostly to the widespread support of HTTP, low overhead, and the existing integration of HTTP within Java web technologies, especially the association between HTTP request and Java Servlet technology. It was hoped this design could be leveraged to allow both local and remote users to access the STIS system, as they would access a typical web-service. When a HTTP request reached the *STIS Servlet*, it was planned that the request data should be extracted, and a new servlet instance and socket

spawned to deal with the request. Socket communication was designed in the system architecture, since it would allow an efficient means of communicating *internally* with the STIS Server, and for retrieving the data from the underlying spatial database.

The HTTP communication link exists between the *STIS Client* and the *STIS Servlet* and was designed to use header information in HTTP POST requests to indicate the type of service request being made. Three types of service request were initially designed,

- A *client data-request*, where an application would request specific information, e.g. coordinates for a particular junction or junctions.

- A *client data refinement request*, allowing an application to get a list of options for a specific input, e.g. listing all the junctions in a particular area, or all the spatial elements with a given name.

- A *journey route request*, which would signal to the STIS server that a route must be calculated from the route request information provided, and a route response returned.

HTTP POST messages were chosen as they are not as restrictive (and are slightly more secure) than HTTP GET. HTTP GET requests were used only to indicate a web-based request, and responded with a fixed HTML response, to be displayed in the requesting user's web-browser. HTTP POST requests were only used with application requests, or in transmitting HTML form information back to the STIS Server.

3.3.3.2 Socket Communications

While chain of communication was defined at an early stage as being HTTP between the client and the servlet, TCP/IP (Java) Socket communications were preferred between the servlet and STIS server. There were several factors leading in to this design choice,

1. Memory was limited, and any system required to handle several concurrent users must either reduce the memory taken up by each thread, or have all threads access a single shared data source.

2. It was envisaged that the STIS system would be deployed on a server in the same local domain as the web-server, but not necessarily on the web-server itself. Therefore some communication was likely required between web-server and STIS-server.

3. Sockets were well-supported in Java, and work reasonably well within a single TCP/IP domain, but tend to suffer with firewall and port issues in intra-domain communication.

This separation of communication mechanisms facilitates a distribution of the STIS system between a dedicated journey planning and routing server, a web-server responsible for HTTP communication with the outside world, and various applications residing remotely, making requests over the HTTP connection to the STIS web-server front end.

3.3.4 STIS Server and Service Layer

The service layer is a grouping of classes whose function is to service the user request, and respond with appropriate data, in an expected format. Additional responsibilities of the service layer include retrieving data from the spatial database, formatting and caching this data, and facilitating data to be sent to the routing planning class to calculate journey routes.

There are a number of main classes which compose the service layer, chief amongst these the ***STIS Server***, which accepts incoming requests (sockets) from the *STIS Servlet*, and spawns a dedicated thread (***STIS Server Thread***) to work on the request, and develop an appropriate response. Since it is not known when the next socket request may be made, the *STIS Server* is put in a permanent loop, waiting for all incoming connections, instantiating new *STIS Server Threads* when needed.

Early project designs did not originally provide a caching functionality, however it was decided to implement a cache which could hold all the relevant spatial data from the ***Spatial Database***, alleviating any load on the database, and improving lookup speeds. This caching functionality was added to the ***Geographic Information System (GIS)*** class, which was initially concerned with only providing geographic lookup functionality, e.g. finding the coordinates of a junction with a give junction ID. The caching of the data required a number of method calls to get and set the data, as well as functionality to retrieve data from the database, and refresh the cache when needed.

The GIS class was selected as the obvious place to situate the cache, since it communicated directly with the spatial database, and already contained functions capable of operating on the spatial data. There are a number of possible caching policies, but it was decided that for simplicity, the GIS should cache all relevant data at run-time, and only refresh the cache on a specific command from the STIS Server. This design choice was made, since the database uses a set of primary keys to index each row in the database tables. Should a row be added to the database without updating the primary keys in the cache, and cache lookups would return inconsistent data.

This pre-emptive caching reduces the complexity of the system somewhat, and provides the requesting user with a level of assurance about the quality of the data provided from the cache.

The GIS class was designed to communicate with the underlying Spatial Database using the ***Spatial API***. The ***Spatial API*** is a Java API developed in 2005 by Thomas Thermin during an internship in the Distributed Systems Group in Trinity College Dublin [17]. This API provides a number of methods for selecting information from the iTransIT spatial database, and is specifically designed to use a spatial context in this selection. For example, a spatial area, or geometry, can be defined, and any entries in the database with spatial coordinates within this geometry are returned (see section 3.3.6).

The final, and most important element within the STIS Service Layer, is the ***STIS Routing Engine***, which is used to calculate journey plans and routes, according to the

parameters set by the user. The *STIS Routing Engine* was designed not hold any routing data itself, such as routing tables, but calculate all journey plans dynamically at run time. The *STIS Routing Engine* must traverse a route through the Dublin road, Luas and bus networks, and provide a response back to the user in an acceptable format. Each transportation method has its own peculiar routing problems and issues, so initially is was planned to develop a separate routing engine for each transport type, however this idea was dropped later on in the design process. The routing engine in essence, polls the ***GIS*** cache for spatial data relating to the particular transport network, and decides on a route which would best match the journey requested by the user.

3.3.5 STIS Client Interface

The client interface is responsible for establishing connections to incoming client requests and sending responses back to the client in a commonly understood format. Since the STIS system is an "on-request" system, it does not spontaneously establish connections to applications and clients, but instead listens for incoming requests, responding to the request over the same communications channel. In this respect the STIS system resembled a web-server responding to requests from users.

It was decided in the early design stage to implement some type of XML interface between the STIS system and the requesting user. This was an early requirement, as the initial project scope did not include any display elements or presentation layer. Due to technical problems in a related project, the proposed XML interface was deemed insufficient, and the client interface was extended to add application data requests and responses. These application requests were included to allow the design of applications in the presentation-layer which did not have to generate XML route requests to display spatial data.

The STIS XML user interface is used to summarise route requests made by the user, and encapsulate the request information in a well recognised format for later retrieval by the routing engine. The resulting journey plane, or route response, is also encoded using XML so the user's presentation layer may get back the information by parsing the XML file.

An XML interface was chosen for a number of reasons including its usefulness as a means of data encapsulation, its broad acceptance generally and the fact that client applications can extract only the information they need, allowing a level of device independence. Against this XML can sometimes prove to be too verbose, that is, too much room is taken up with formatting that could more easily be used for useful data. Sending large amounts of XML-encoded data to a mobile device with limited processing resources and memory could lead to the device being, for practical purposes, rendered useless.

3.3.5.1 Route Request XML

Two XML schemas were designed for this project, one to describe journey routes, and the second the route response. Since both the presentation layer and the STIS system would have to agree on the data, a number of terms were specified to help define routes, and spatial information. The "start" point was defined as the user-specified point of origin for the journey, and the "destination" point was the user-specified end-point for the journey. The waypoints are intermediate journey goals, which must be visited on the journey, between the start and the destination, in a pre-determined order. The Route Request XML basically describes the route request, detailing the time when the request was first made, the preferred travel mode, the start, destination and various waypoints, which combine to describe the request.

```
<?xml version="1.0"?>
<RouteRequest>
        <details>
                <date>Mon Jun 16 11:00:00 BST 2006</date>
                <requestType>1004</requestType>
                <travel-mode>cycling</travel-mode>
        </details>
        <start>
                <type>Street-Name</type><value>Phibsboro Road</value>
        </start>

        <destination>
                <type>Luas-Stop</type><value>Museum</value>
        </destination>

        <waypoints>
                <waypoint>
                        <type>Junction-ID</type><value>1295z</value>
                </waypoint>
        </waypoints>
```

Figure 18 - Route Request Example XML

There are a number of subtle nuances contained in the Route Request XML file, which are not immediately obvious. Firstly each start, destination and waypoint value has an associated “type”, which is used to identify elements as being a street-name, junction-id, bus-stop, OSI coordinate value or Luas-stop. The design allows for the types to be extended to include elements such as other modes of transport (e.g. DART stations), area names, or even area geometries. Since there were only three types of spatial data in the iTransIT database (roads/bus/Luas), there was no opportunity to include other modes of transportation, but these can be added quite easily to the system. The only changes required to the system would be to create a new table in the iTransIT database, and associate that with a given type.

The route request also lists the preferred mode of transport separately from route waypoints, which allows the freedom to route between any number of points in a preferred mode. This would allow for example, a user to specify two bus stops as journey parameters and yet walk between them. An extension of this preferred mode of travel would be to list the preferred modes of transport in order, routing between journey waypoints according to the available options. Due to time constraints this was not implemented but is supported in the design.

The waypoints are listed in order, so that the first waypoint encountered in the Route Request XML will be the first point visited directly after the starting point. Likewise the last waypoint listed in the XML file is the last visited point before the destination. The route traversal, from the starting point to the destination via any number of waypoints, allows sub-routes to be calculated independently and eventually concatenated to form the overall journey. It was planned to allow different preferred transportation modes between specified waypoints, but this flexibility was not required, instead a single preferred mode of transport was deemed enough to provide a means of routing according to the user’s wishes.

3.3.5.2 Route Response XML

The Route Response XML is the output from the STIS System, and is used to describe the route elements, and route links individually, which when added together constitute the journey. A route link was considered to be the link between two adjacent route elements in the XML.

```
<?xml version="1.0"?>
<RouteResponse>

        <response>
                <date>Mon Jun 16 11:00:00 BST 2006</date>
                <latency>10 ms</latency>
        </response>

        <route>
                <details>
                        <duration>
                                <total>1 hour, 21 minutes</total>
                                <mode type="walking">30 minutes</mode>
                                <mode type="luas">51 minutes</mode>
                        </duration>
                        <distance>
                                <total>700.0m</total>
                                <mode type="walking">555.0</mode>
                                <mode type="luas">145.0</mode>
                        </distance>
                </details>

                <links>
                        <linkElement>
                                <id>874</id>
                                <name>O'Connell Street</name>
                                <type>street-name</type>
                                <geometry>POINT(123456 123456)</geometry>
                        </linkElement>

                        <link>
                                <mode>walking</mode>
                                <duration>10.0</duration>
                                <distance>155.0</distance>
                        </link>

                                .
```

Figure 19 - Route Response XML example

The main goal of the route response XML file is to list, in order, the link elements along the journey. To do this the route response contains all the necessary data to match each link element back to it's originating entry in the spatial database, as well as providing the information necessary to re-construct the route on the client side. It was intended that the route response XML should contain enough data so that the route could be re-constructed even if the spatial database was not accessible by the client. To this end, the spatial coordinates of each point along the route would be

provided, along with the mode of travel, and the pre-calculated link distance and duration.

A client receiving the route response XML file would be able, to a large extent, to recreate the route using only the information available in the XML response. No spatial calculations would be required at the client-side, neither would any summary calculation of the journey distance or duration be required.

This design decision was made to facilitate the construction of "light-weight" client applications, which needed to know little or nothing about the underlying routing functionality or travel modes. The multi-modal aspect of the route response is support by listing each link according to it's mode of transport, as well as providing a synopsis at the beginning of the XML file, describing the total distance, and period of time taken by each different mode of transport. This approach means that the system is readily able to adapt to changes, and can add new modes of travel, or spatial objects, quite easily the route response.

3.3.5.3 Application-Level Requests

In addition to an XML routing interface, there was an emerging requirement during the design phase, to support an application level request/response interface, which would query for individual pieces of data rather than whole routes. Again these were encoded in small XML strings, using <Client-Request> tags, along with type and value to distinguish the piece of information being sought.

3.3.6 Spatial API Interface

All the information required by the STIS system is stored in a database, accessible via a Spatial API. The Spatial API was developed from work done in the iTransIT project [20]. This Spatial API, implemented in Java and using various JDBC third party libraries, was designed to fetch data from the "spatial" database, allowing data retrieval based solely on user-provided spatial coordinates, or other parameters.

Initially, since the project called for a rapid prototyping approach towards system design and implementation, it was essential that the travel data sources be accessible locally, as the development work was principally carried out off-line. The design plan called for an initial implementation using a locally installed database, connecting to the remote (live) database server when a sufficient level of functionality was developed. The early prototypes connected directly to the spatial database using standard Java Database Connectivity (JDBC) libraries to set up a remote connection, and execute SQL queries. When the JDBC was established, and the database link verified, the next stage was to implement the Spatial API in place of the "direct" JDBC link.

This process of first testing with the "direct" database connection, followed by the Spatial API connection allowed applications and routing algorithms to be verified, as well as providing an insight into the strengths and weaknesses of the Spatial API.

The Spatial API implementation provided a number of operations which were used to insert and update data in the database, as well as retrieving information based on a user-provided primary key, table name and column name. There was no use, in this project, for the retrieval of spatial objects based on their location, since the majority of requests to the API were for either all the elements of a particular type, or a named (and indexed) element of a particular type. This, coupled with caching the spatial data within the GIS class, made this feature of the spatial API redundant.

The table and column names in the spatial database are required in order to provide parameter values to the spatial API methods. The tables used in the spatial database are outlined in the documentation [17], but in essence there are four main tables,

- R_D_Junction table containing all the junction data.
- R_Link table containing all the link information to do with junctions.
- R_LuasStop table giving Luas stop information.
- R_BusStop table giving Bus stop information.

There were also a number of secondary tables used to list the routes between Luas and Bus stops, but these were used less than the other parameters. The parameters are entered in the spatial API information retrieval methods. There are a number of retrieve methods specified by the API, but two in particular proved invaluable to the STIS system design. The first retrieve method takes in as parameters, the table name, and parameter name, identifying a particular column in the spatial database, (e.g. the junctions table "R_D_Junction" and "geometry"). A call to this method would return the list of all column elements of this parameter type. The second useful retrieve method used by the STIS system is similar to the bulk retrieve method, except it allows the row as well as the column to be specified in the database. A retrieve request made to the "R_D_Junction" table listing the row auto ID (primary key) and parameter value (column name) would return the contents of a particular "cell" within a row in the database. The combination of these two retrieve methods formed the back-bone of the STIS communications layer.

3.3.7 Concurrent User Requirements

There was a requirement from the outset to support an unspecified number of concurrent users. This required that multiple communications streams must be supported, in parallel, to the STIS system. In addition, the travel information need to be distributed to each requesting client, so that journey routes could be calculated. This proved somewhat of a design headache since Java does not allow references to data structures to be shared outside a single class, but instead passes a copy of the data structure, as a complete instance, between classes. Due to the large amounts of data being cached by the STIS system, duplication of this data (by passing instances of the cache between classes) would quickly have consumed the all the available memory.

Rather than duplicate data for each separate thread, it was intended to use a STIS server to maintain (and cache) all the spatial data in a single place, allowing concurrent clients to connect to the shared data in parallel. Socket communication, specifically server sockets and multi-threading, are well supported in Java, and allowed an efficient means to take incoming HTTP requests, and spawn a thread and onward socket dedicated to servicing the request. This socket communication was supported on the server side by the STIS Socket Client, which would tie together the STIS Servlet (support the HTTP connections to the clients) with the STIS Server containing the single instance of the cached spatial data.

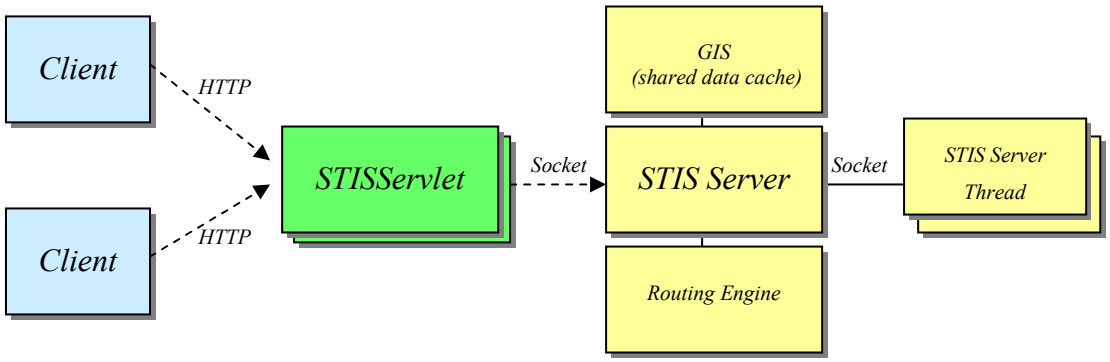

Figure 20 - STIS Communication Structure

A client connection to the STIS Server would initially use a HTTP connection to the STIS Servlet, and would in turn connect to the STIS Server via TCP/IP sockets. The data transmitted over both communications protocols would remain the same, i.e. XML. A HTTP connection was designed to provide a communications front end since HTTP more easily evades problems associate with socket communications – mostly because of the way HTTP is accepted over most networks whereas "raw" TCP/IP packets are rejected.

3.3.8 Design Features added during Implementation Phase

In common with most substantial coding projects, there is a degree of addition to the design as the implementation phase progresses. This project was no different, and a number of extra design features were added as a direct result of observations made during the initial prototype implementation.

Since the design and implementation of the GUI interface is the most "ad-hoc" design process in the project, most of the additional features added during the implementation phase, were added to the GUI interface.

There were a number of predecessors which provided an example of how mapping and routing web-applications should be implemented. Foremost amongst these were the two leading internet map providers, Map24 and GoogleMaps. Features such as dragging the map, and providing refinement feedback to the user were inspired by features present in these existing web services.

Unlike both of these web-services, the Map Viewer front-end was designed as a standalone application, and draws it's inspiration from high quality open source Java applications such as SQuirreL[21].

3.4 Designing the Transport Network Model

Finding a route through a city streets requires two essential elements, firstly a model of the streets themselves, and secondly an algorithm to find an efficient route through this model.

Each node in the transport network (junction, Bus stop, Luas stop) must be represented using its geographic position, and unique node identifier. In the case of road junctions, a naming system existed in the spatial database uniquely describing each junction with an alpha-numeric code, such as "1255" or "981z". Luas Stops are identified by their unique names, taken from the Luas network routes themselves. Dublin bus stops are more complex, in that many bus routes can use the same bus-stop, and there can be many bus stops located on a single street. The bus stop identifiers used are a combination of the street-name of the bus stop and integer, in order to uniquely each bus stop.

Extra information about each transport network node is also required to model the network correctly, this begin the list of all links between nodes in the network. In the case of the road network these links are the streets connecting neighbouring junctions. Luas and Bus networks, while using some existing road junctions, are conceptually

linked from stop to stop, rather than listing the (unnecessary) intermediate road junctions between stops.

3.4.1 Modelling Dublin's Transport Links

One widely accepted method of representing a street-map, or any geographic area, is to represent the map features as vertices in a graph. A map of Dublin streets can be defined as a directed graph with a set of vertices (junctions) which are interconnected by a set of edges (streets/roads). A directed graph is one where each link may be traversed in one direction only. This feature is important in a model of a street-map, since some streets may be one-way streets, whereas others may allow traffic to move in both directions, represented by two separate links.

Directed graphs used to model geographic areas or road networks are sometimes referred to as Euclidean networks, defined as graphs "whose edge weights are defined by geometric distances between the points" [22].

There are a number of peculiarities which must be included in the model of any road network in Dublin. The topology of the directed graphs must closely model the layout of the road junctions, and provide an accurate position for each node (junction) in the graph in relation to the rest of the vertices. Luckily a mapping datum exists which provides the coordinates of each junction in Cartesian space. This datum, referred to subsequently in this document as the "OSI mapping", is the Ordnance Survey Ireland mapping datum for Ireland.

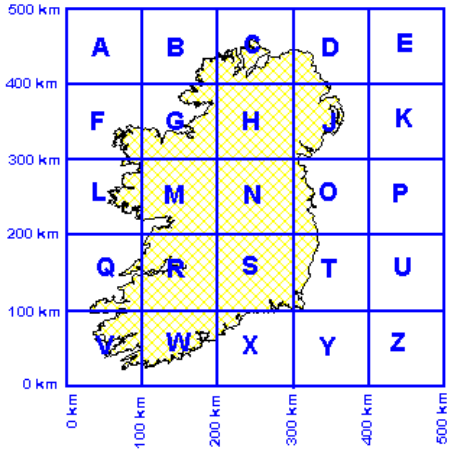

Figure 21 - Irish National Grid, see reference [2]

The OSI mapping datum can be used to specify a coordinate tuple for each node in the directed graph, using the easting and northing coordinate system. This is essentially an x-y Cartesian projection, which uses the X and Y coordinates as measured in meters, with an origin point in the south-west corner of each sub-grid. The x-axis increments positively from west to east, whereas the y-axis increments (in meters) going from south to north. It is useful at this time to point out that this mapping datum is specific to Ireland, and has no direct correlation to the WGS-84 mapping datum (more usually knows as latitude/longitude).

Coordinates specified using the OSI map projection, are typically of the form (315000, 235000), the first value described is always the X-coordinate, and the second the Y-coordinate. The values themselves are meters from the origin point.

3.4.2 Interconnection between Transport Links

In addition to a specific mapping datum for Dublin, there are also separate junctions assigned for varying types of transport services. This project covers three main transport services, the road network (walking, cycling, driving etc.), the Dublin bus network (which sometimes uses special bus lanes), and the Luas tram network, which runs on special tracks along certain roads, sometimes shared with vehicle traffic.

The design process called for a graph for each transport mode, but obviously walking, cycling and driving will share the same road network. The Luas tram service uses separate lanes to the regular road network, however the Dublin Bus network, whilst utilising the road network, can be described using a reduced directed graphs, since the direction of travel is pre-ordained for each bus route.

3.4.3 Generating Traffic Congestion Data

The iTransIT database is supplied with congestion data taken from a traffic simulator, developed as part of a related study within the iTransIT project. This traffic simulator was used to produce numeric traffic congestion information, matched to a particular junction. This numeric data was then inserted in the appropriate row in the spatial database, in the "congestionLevel" column.

The congestion levels range from 0 indicating light traffic, to a maximum of 7, indicating heavy traffic congestion. The simulator itself was very processor intensive, and did not produce much in the way of congestion information. Ideally, if there was an interface from the iTransIT spatial database to Dublin Corporation's traffic measurement system, the real-time traffic data could have been used for this project.

The design of the system reflected the potential for expanding the spatial database to include more current congestion data. Since the link between the source of traffic congestion data is abstracted behind the iTransIT spatial database, and changes to the system would be at the database layer, and not impinge on the operation of the STIS system (beyond providing better congestion information).

3.4.4 Changes in Network Topology

The topology of the road network is assumed to be relatively static. Changes to the road network are typically very slow, and any such changes that do usually occur (such as changing one-way street directions etc.) can be easily modified in the model of the road network. The routing functionality was designed to be dynamic (see section 3.5), so any changes to the network topology which are committed to the spatial database, will be automatically reflected in the STIS system. This has a great benefit, in that there is no need to re-compile any routing tables, or make any changes to the routing algorithm.

Occasionally, certain dynamic topology changes, due to traffic accidents, road closures, etc. can occur quickly and revert to their "normal" state in a matter of hours or days. These changes also could be committed to the database, and noted by the STIS routing functionality.

The bus network is subject to two likely sources of change, the bus company changing routes, schedules and timetables, and changes forced on various routes due to road closures, and other traffic measures. Again, the design of the system can accommodate changes, once the changes are made to the database.

The two Luas routes are not interconnected, and any route or timetable changes are most often localised on only one Luas route. Sometimes, the Luas routes are subjected to delays at tram/road intersections, and very rarely due to traffic accidents at or near intersections. It is likely that the Luas Green line will be expanded in the short term by adding extra stops, again similarly to the Bus routes this change can be easily accommodated by the system.

3.5 Routing Algorithms

The type of route finding problem outlined by the STIS project requirements, is a classic problem in the area of computer science and graph theory. Finding the most efficient path between two connected nodes in a network has been well studied, and much material existed in the area which was incorporated into the routing algorithm design. These types of routing problem included such diverse areas as the mathematician Euler's travels across the bridges of Königsberg, the well-known travelling salesman problem, and the design of microchips and PCB's, all of which require the optimal route to be found. This optimal route is typically the route which minimises the associated cost of travelling between the two nodes, often expressed as a function of shortest distance covered, or fastest time.

A shortest path routing algorithm would use various inputs to select the optimal route, for example by evaluating a number of factors such as:-

- The overall distance covered by the route.
- The modes of travel to be used.
- The overall route duration.
- The number of intervening waypoints.
- The general direction of travel.
- The size of the roads.
- The direction of the roads (i.e. one-way traffic systems).
- The local traffic congestion.
- The public transport times/schedule.

A weighting associated with a path through the network can be found using a function of one or more of these metrics. The shortest path through the network would be the one which minimises this combined weighting.

When researching the way similar traffic routing functions were implemented [23], it was found that user's typically were assumed to select the route taking the least time, rather than the route with the shortest distance travelled. This core assumption formed the basis for the implementation of the routing algorithm.

3.5.1 Dynamic Route Calculation

In a closed network, such as the Dublin road network as contained in the spatial database, it is possible to pre-calculated route information, by compiling tables giving the shortest paths between all neighbouring nodes in the network. This pre-processing, whilst providing a degree of efficiency at runtime, has drawbacks, primarily the static nature of the information once calculated.

A design decision was taken therefore to consider only dynamic routing calculation, rather than pre-processed, or table-driven, routing algorithms. This was due to the fact that the system was planned to reflect rapidly changing conditions (such as traffic congestion) as inputs into the routing algorithm. Additionally, it was expected that any routing algorithm developed for the STIS server should be capable of deal with an expansion of the road networks without having to be re-written.

Dynamic route calculation has an extra cost associated with the performance of the algorithm. While this means a dynamic routing algorithm proves less efficient overall, it does provides a freedom and an extensibility necessary for this project. The STIS system is a middleware platform, designed for use with legacy travel data sources, and as such must accommodate change within its design, and allow the for the addition of information to the database without adverse effects to the STIS system as a whole.

3.5.2 Exhaustive Shortest Path Algorithms

There are a large number of exhaustive shortest path algorithms, which all share a number of common features. The basic operating principal of each of these algorithms is to traverse the graph a link at a time, spiralling out from the starting point, until either the destination point is reached, or the entire graph is traversed. The partial paths built up from the graph traversal are used to construct the shortest path. These algorithms are exhaustive, in that all links are traversed in until the destination vertex is arrived at.

An exhaustive search algorithm is guaranteed to produce the most efficient path, i.e. that which is guaranteed to be the shortest path. This guarantee comes at a significant cost, chiefly their extensive time-consuming traversal of the graph, as well as consuming large amounts of memory and processing resources during the search. Except in very small graphs, or where the finding the absolute shortest path is critical, the drawbacks of exhaustive search algorithms all but preclude their usage in large directed graph structures.

Exhaustive shortest path algorithms include breadth-first and depth-first search, as well as more complex algorithms such as Dijkstra's algorithm[24], Lee's Algorithm [25] and the Bellman-Ford routing algorithm [26]. The most well known of these, Dijkstra's algorithm, has computational costs equivalent to the square of the number of vertices (i.e. $(Vertices)^2$) to be searched. Other algorithms, such as the Bellman-Ford routing algorithm, have similar costs, on the order of *Vertices x Edges*, where the edges are the links between vertices in the graph [22].

For large graphs, such as the model of Dublin streets, there are approximately 1300 vertices and 2800 edges. It is not too surprising therefore to conclude that exhaustive search algorithms do not provide a shortest-path route in an efficient manner through such a large graph structure.

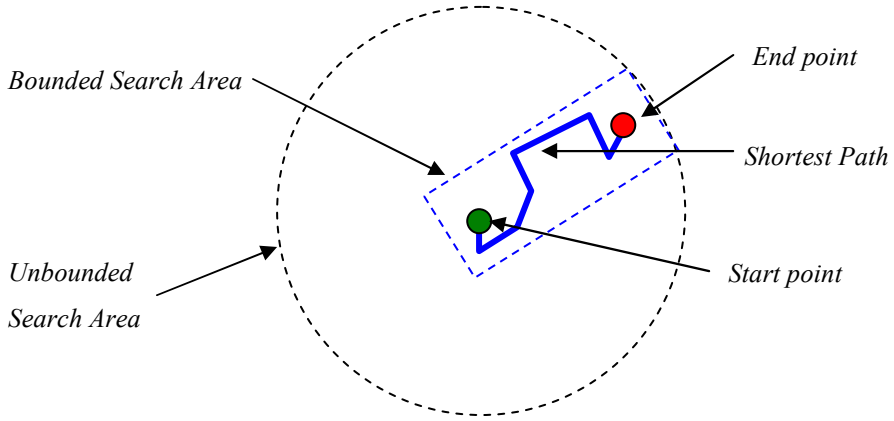

Figure 22 - Exhaustive Search Space, and Bounded Search Area

There are means to reduce the computation costs, such as by selecting a subset of the vertices deemed relevant to a given search. This directive can be used to restrict the search space, creating a sub-set of all the vertices in a bounded area between the start and end points, thereby limiting the shortest path search to this area. Again, this pre-selection, while reducing the time spend traversing the graph nodes, still contains an inherent inefficiency since a certain number of the nodes traversed in the bounded area will not prove useful.

3.5.3 Table-based Routing Algorithms

There are many internet routing algorithms, but a popular early routing algorithm involved regularly calculating the cost of traversing the links to all its neighbours, and saving this data in a table which could be then used to quickly route data packets to their destination. This table-based, or table-driven routing method has the advantages of being very efficient when setup correctly, with the main disadvantage of poor performance where the topology of the network changes or the cost of taking a particular route alters.

A table-based routing algorithm for traffic routing would implement a similar scheme, pre-computing the likely cost of each link in the graph, then using this pre-compiled information to select links for a route. A draw-back of this calculation is that it would be required every time a change was detected in the network. For this reason principally, the use of table-driven routing algorithms was ruled out for the STIS routing algorithm, due to the dynamic content in the database (e.g. traffic congestion information), and the expected frequent updates to the data.

3.5.4 Heuristic Driven Shortest Path Algorithms

A heuristic driven shortest path algorithm is one which does not exhaustively trawl the entire search space, but instead selects vertices along the route based on some rule, building up a shortest path a node at a time. The rule used to select the next vertex along the route is, in effect, a sorting of the candidate nodes according to a given fitness criteria.

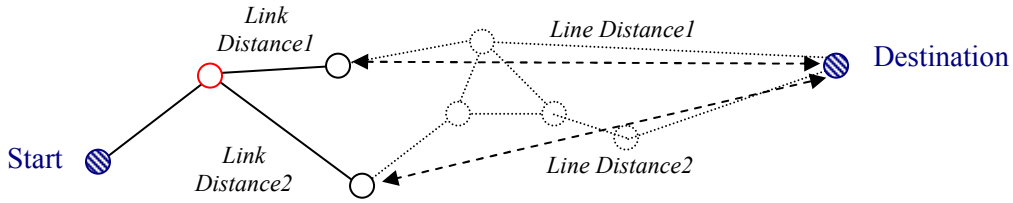

Figure 23 - Distance-based search heuristic

This type of algorithm is sometimes referred to as a priority-first search, since at each step the various routing options are prioritised, and the "best" candidate selected.

For the STIS routing algorithm, it was decided that the best strategy would be to implement a simplistic priority first search, which sorts the candidate links based on the sum of the link distance, and remaining distance to the final journey destination. This type of heuristic ensures that vertices are only visited once along the route, reducing the amount of time spent finding the route. What the heuristic does not do is ensure the route selected is the shortest path between the two points, however due to the high node density of the graph representing Dublin streets, the margin between the shortest part and the route produced by this algorithm is very small.

This approach was selected as the routing algorithm, as it will find a route through a graph in a time which is proportional to the number of links along the route, rather than the size of the overall graph. For a graph representing the Dublin road network this is a paramount consideration, as it allows road to be added without affecting the performance of the algorithm. The graphs representing the bus and Luas networks were much more sparsely populated, and a slightly different approach was required, which added a number of extra checks to ensure the routing considered lines/bus routes as well as overall direction of travel.

Originally it was intended to implement a look-ahead feature within the routing algorithm which would advance a route calculation to ensure that the overall direction of travel was towards the destination. However due to time pressures caused by the development of the presentation layer, there was insufficient time to test and deploy this functionality.

3.5.5 Finding Multi-modal Routes

Multi-modal routes were defined as those which utilised at least two different modes of travel during a single journey. This requirement increased the complexity of the routing problem, since the various transport modes where described using separate directed graphs representing the travel links, with the only "key" tying each graph together being the spatial coordinates of the links within each graph/travel mode. For example, the bus and Luas routes could be associated with junctions using their spatial coordinates.

To further complicate matters, some networks, such as the Luas and Bus networks were disjoint, with various separate links forming completely separate sub-graphs.

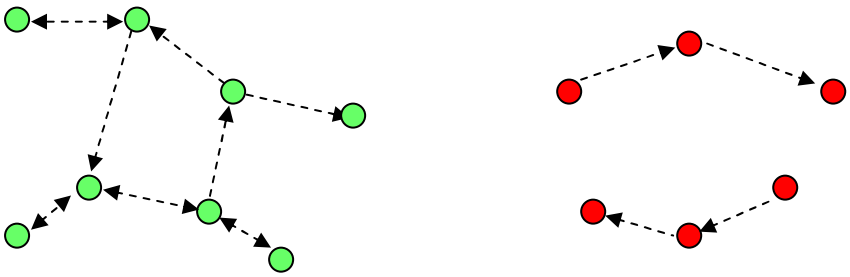

Figure 24 - Fully connected graph (left) and a disjointed graph (right)

The spatial coordinates were designed to "stitch together" the various routes and combine to form a multi-modal route. For example, in a disjoint network, such as the bus network, any unconnected vertices in the graph (bus-stops) would be linked by finding the nearest road junction to the spatial coordinates of each vertex, next calculating the road route between the two junctions. A notional connection would be

added then between the bus-stop and the nearest junction. The typical distance from a bus stop to a nearby junction would be typically on the order of several meters.

The road network was a fully connected graph, where each vertex (junction) in the graph could be reached from any other. The Luas and Bus networks were disjoint graphs, with "gaps" between some vertices. To further complicate matters, the links between vertices in all graphs were often "one-way" links, which would impact upon the allowed direction of travel between different vertices.

The design of the routing algorithm needed to ensure that a link between two separate points be traversed using one or a number of modes of travel. A design decision was taken early in the project to allow the user to select a preferred mode of travel, and calculate a route using this mode as must as possible. Where an entire route between two points couldn't be achieved using the preferred mode of travel, the remaining sub-routes were added using a default pedestrian mode. This meant that any Luas or Bus route between two specified points would either be on bus or tram, defaulting to a walking route where needed. This choice simply reflected the modes of travel which were specified by the project proposal, as well as the simple fact that cyclists and vehicle users are more likely to complete their route using their respective means of travel.

While the STIS system was designed with only one preferred mode of travel to be specified (defaulting to walking when required), the core functionality is easily adaptable to allow users to list different preferred modes between different waypoints along the same route, or even providing a number of preferred modes of travel listed in order of preference.

4 Architecture Implementation

"I don't wanna live in a city where the only cultural advantage is that you can make a right turn on a red light" – Woody Allen

The software for this project was planned, from the beginning, to be executed in a Java (J2SE) environment. This implementation decision was taken due to the popularity of the Java, its platform independence, and its straight-forward integration with existing web and database technologies.

Related technologies, such as Java Servlets, and Java Database Connectivity (JDBC) libraries allowed a smooth implementation process, reducing any inter-working problems between components in the design. The implementation process itself, was a rapid prototyping model, whereby software was created, tested, and any lessons learned were fed back into the next design cycle. In total twelve such design-implement-refactor cycles were completed for the project, producing in the end over 10,000 lines of code.

In parallel with the rapid prototyping model, a number of automated test-cases were constructed to ensure the software produced was (reasonably) reliable, and performed as expected. JUnit test cases were produced, and used extensively to verify the operation of various classes implemented for the STIS project [27]. JUnit was especially adept at verifying the operation of data retrieval and spatial calculation functionality such as was present in the GIS class, and STIS routing engine. JUnit did not provide any benefit when it came to the testing system's graphical components, and many hours were spent manually testing various GUI interfaces, image generation functionality and graphic layouts.

There was no early design road-map or work-plan, however the overall intention was to create an early stable prototype(s), moving on then to the final software implementation for mid to late August 2006.

There were three essential elements to the architecture implementation,

1. A means of accessing the spatial data held in a database, and translating this data into a useable form.
2. Develop a multi-modal routing engine, which would evaluate a route based on a number of user-input parameters.
3. Create a means of visualising the routes returned from the routing engine.

There were a number of early (rapid) prototypes developed as proof of concept and as a means of refining the design for the final software implementation. The tool used to test the output from the STIS system, the Map Viewer application, was eventually included in the overall project output.

4.1 Software Implementation History

The software implemented as part of the STIS project was based on work done earlier [17]. As part of this earlier implementation, a number of XML files were used to describe the junctions in the road network, as well as data listing Dublin bus stops. These XML files were used in the early stages of this project to provide some workable static data for initial early prototype implementations. When the implementation developed, the static data read from the XML files was replaced by the Spatial API connecting directly to the database.

The software implementation can be divided into roughly three phases, or iterations. The first stage, known as the ***Alpha prototype***, was used as a test-bed for some of the GUI elements of the design, and as a means of providing workable data for the later prototypes. The first prototype was a relatively simple map frame GUI which displayed the location of the junction data on the screen, overlaid on a static graphical map. It was found that the road junctions, when drawn on the map, were offset (skewed) by a variable distance from their correct position on the map. To correct this disparity, a fixed skew or rotational value was applied to each junction OSI co-ordinate to place it correctly on the map. This OSI to X, Y coordinate conversion was done visually, using a bespoke mapping tool to scale, skew and translate the coordinates until a correct “fit” was achieved. The OSI coordinates themselves were

not altered in any way, and the coordinate conversion operations were contained in a method in the GUI class.

The principal implementation phase added to the work done on the Alpha prototype, introducing a number of new features such as JDBC connections, Spatial API (S-API) requests, and improved user features. This ***Beta prototype*** re-factored the previous Java code to improve the overall performance, and add new functionality. Typically a new release of the software was made once a week, or whenever a sufficient amount of new functionality had been added and tested. Initially the spatial information, such as the junction coordinates, the link information, and the data on Luas and Bus stops, were taken (parsed) from the Paramics XML files. However a JDBC connection was integrated allowing a direct retrieval of the data from the spatial database, followed by the integration of the spatial API's to perform the same type of function. After evaluating both methods, it was decided to keep both the JDBC and S-API functionality for evaluation purposes, and implementation efficiencies. The time taken for the JDBC "direct" connection to retrieval all the required spatial data from the database was on the order of 2-3 seconds, however the performance of the S-API was much slower, and prone to exceptions, so the JDBC connection was largely used during implementation. The Beta Prototype added a web front-end to the existing map frame GUI, as a means of allowing remote users to access the system. In addition various releases included new features such as street-name lookups, journey waypoints, and route distance/time estimates.

The final phase of implementation was a complete re-factoring of the Beta prototype code, and introduced some important design features such as complementary JDBC/S-API requests, a standalone STIS Server, and the caching of spatial data in memory for efficient retrieval later.

4.2 Software Releases

22nd May 2006, ***Alpha prototype*** test, which displayed the junction and link information overlaid on a zoom-able map of Dublin. This prototype also served as a tool to re-align the coordinate system to correctly match the road layout.

3rd June 2006, ***Alpha prototype*** completed and released. A number of new improvements to the GUI added, however all junction, bus and Luas data was still retrieved from the Paramics XML files

6th June 2006, ***Beta prototype*** version 1.0 released. This added GUI improvements, and displayed correctly the location of junctions, as well as Luas and bus stops. There was no routing functionality as yet, and the Paramics XML data still provided all the spatial information.

23rd June 2006, ***Beta prototype*** version 1.3 released, adding Servlet front end to the system. Versions 1.1 and 1.2 were terminated early, and work continued with 1.3. An early routing system was added allowing a route to be calculated between two named junction ID's. No multi-modal routes were supported, and a number of data encapsulation classes were added, the Route Request and Route Response classes, to describe information useful to the STIS system.

25th June 2006, version 1.4 improves the routing functionality, differentiating between journeys compelled to use the one-way street-system (vehicles and cyclists), and journeys which can go against the one-way street-system (pedestrians). In addition methods were added to the Route Request/Response classes to generate an XML string representing data in the object, as well as constructors to re-initialise the object from the XML.

30th June 2006, version 1.5 all the spatial data request functionality was moved to a new GIS (Geographic Information System) class. This class was to provide convenient wrapper methods for requests to the spatial data.

12th July 2006, version 1.6, street-name validation methods added to allow a user to initiate a route request by providing a street name as a string. This version required creating a mapping file between street-names and junction ID's, and a script to update the spatial database with this extra information.

25th July 2006, ***Final Prototype*** version 1.8, addition of the Spatial API and extensive code re-factoring. Version 1.7 was a non-working version, which was abandoned earlier, allowing development work to be concentrated on finishing version 1.8.

5th August 2006, Final Prototype version 1.10, integrated a stand-alone STIS server class, which would provide a cache for the spatial data after requesting the information from the spatial database. Development work on version 1.9 was abandoned in late July 2006, due to socket communication bugs.

10th August 2006, Final Prototype version 1.11. The communication between the client application and the STIS server was changed from socket communications to HTTP to allow remote testing of the application.

25th August 2006, Final (Demo) Prototype version 1.12. The software was re-factored, and some bugs removed from the routing functionality. The servlet front-end scales the graphics returned from the map generator, and the socket client was altered to be more resilient in the event of failures.

4.3 Implementation Issues

A number of fundamental issues relating to routing and journey calculation were exposed during the implementation process. Since the design and implementation process used during the project was iterative, any findings were fed into subsequent versions of the software. The following sections describe the main obstacles faced during the implementation of the system.

4.3.1 Coordinate Transformation

The OSI coordinates, as provided by the database (and iTransIT Paramics data [20]) were found to be offset and skewed, when overlaid on a street-map of Dublin. Much work was required to scale, translate and rotate the coordinate plane the road links as described by the system corresponded to an accurate street map of Dublin.

A mapping tool was developed which assisted in calculating the offset and skew value associated with coordinates retrieved from the database. It was found that a fixed

offset and skew value would correctly map the OSI coordinates to their apparent correct position on the map of Dublin.

4.3.2 Associating street-names with junctions/links

The data provided as part of the original work did not associate any street-names with the existing numeric junction identifiers. There were approximately 2800 streets (links) available, of which only 470 were classified according to their street-name for this project.

This mapping between junction identifiers and street-names required that each street-name be matched to one or more appropriate rows in the "R_Link" table of the spatial database. Finding this matching was accomplished using the Map Viewer tool, manually recording the database junction id values for each street, and then entering this data into the database. This tedious process required many hours of careful work, so only a limited number of roads were input, mainly for demonstration purposes.

4.3.3 Route Validation

The route selected from a given set of user inputs is returned to the requesting user as an XML string. This text output on its own cannot be readily validated, except for comparing the start and destination points, and the overall mode of transport.

During the implementation part of the project, the validation of the overall correctness of the route itself was performed by producing a route map from the XML data, and visually inspecting this map. The Map Viewer application was capable of displaying the routes, coloured coded according to the mode of transport.

There is a basic inbuilt routing check performed by the STIS routing engine class, where a multi-modal route is compared to the road distance between the start and destination points. If the multi-modal route distance is a much greater distance (at least double) the road distance, the road distance is selected. There was not enough time at the end of the project to implement an in-built route validation mechanism, but given more time a number of route alternatives could be calculated in parallel, and the “best” one returned.

4.3.4 Map Visualisation

For the purposes of this project, two large scale graphic maps of Dublin were compiled from a well-known online map provider. These maps were used as the underlying street-map of Dublin over which were overlaid the various junctions, bus stops and journey routes.

The implementation of both the Map Viewer application and the STIS routing engine use Java Graphics2D functionality to draw the overlay graphics on top of the underlying static maps. This composite image is presented directly to the user in the Map Application, but saved as a JPEG image in the case of the STIS Servlet.

The STIS Servlet uses an in-memory canvas on which to draw the composite image to be saved to disc. This extra operation is required as there is no facility to directly display the canvas in the frame of a web-browser.

4.4 Security Considerations

For the purposes of this project, the system not be "live" in the sense of a traditional web-service, however it will be at a level sufficient for live operation. The following sections will therefore assume the worst case scenario – i.e. the system is a publicly assessable live web-service.

There are a number of security considerations which impact on the system, either directly or indirectly. The operation of the Smart Traveller Information System is somewhat analogous to a web-server connected to a back-office information system.

4.4.1 Dependencies on Third-Party Software

The STIS system makes use of a relational database to store information relating to the travel information. The database chosen for the project was the open-source MySQL server version 5.0.1. The benefit of using MySQL over a proprietary database is in the fact that the open source nature of this popular software lead to any bugs being readily exposed and corrected, limiting the number of potential flaws which could be exploited by any malicious users.

The STIS server utilises the TomCat 5.5 web-server to facilitate communication with both the clients in the presentation layer. Equally as with the database implementation, being open source the web-server software can expect close scrutiny for security vulnerabilities, and, it is hoped, timely interventions once security flaws are exposed.

4.4.2 Insecure Default Configurations

For ease of implementation the STIS system was designed to be deployed on a Windows XP environment, accessing information from the remote SQL database, using the TomCat web server to provide a web-based front end.

The TomCat web-server, is typically installed without security options enabled, and comes initially installed with a well-known initial admin username and password (root/root). This well-known initial login is also an issue with many database installations. The obvious solution to this vulnerability is to deploy the system on the network only when the root username and passwords have been changed to a secure (non-guessable) text string, and this entrusted only to the system administrators.

4.4.3 Server Hardening

Typically, if a mission critical system is to be deployed, or made publicly available, the server goes through a process known as hardening. This process does not usually involve much in the way of changes to the system hardware, but usually requires patching the operating system and system software components, as well as closing communications mechanisms and ports which are surplus to requirements.

Unfortunately, the server used for the STIS system is a laptop in everyday use it is more vulnerable to industry level servers. There area however benefits, mainly by the fact the STIS server is protected primarily by the Trinity College firewall from external users. Hardening the STIS service is not a strict requirement, and was largely unnecessary for this project. However the system is slightly vulnerable to malicious users inside the TCD firewall, or malicious users targeting the TCD domain as a whole. A simple denial of service bug could be easily accomplished by sending oversized XML requests to the system, which would slow the STIS system to a standstill.

4.4.4 STIS Software Security

The code developed for the project could itself be the source of security loopholes. There was extensive used of XML in this project, and some XML parser implementations can cause errors and crashes when submitted with malformed XML information. This vulnerability was described in a recent dissertation paper from Trinity College Dublin [28]. Vulnerabilities caused by the XML parser are a product of bad software within the parsers themselves, and can only be overcome by using well tested parsers with known failure semantics.

This vulnerability was side-stepped by the STIS system, since all XML parsing is performed using bespoke functionality in the software, rather than a well known third party product.

4.4.5 STIS Failure semantics

The design of the system was intended to minimise the effects of a client failure on the server side. Since a client connects via a HTTP interface to the STIS Servlet (and on to the STIS Server), any client failures should result in no further HTTP requests being received on the server side.

The STIS Servlet acts as a front end to the server side, and passes on HTTP requests over a socket interface to the STIS Server. This socket interface is opened and closed on the reception of messages from the Map Viewer client, and automatically in the case of the web-browsers connecting to the STIS Servlet.

The failure of any socket connection results in the STIS Servlet attempting to re-connect the socket connection on the next message received from the client. There is no provision in the STIS system provided for socket timeouts given that there could be large periods of time between a single client making consecutive requests.

There exists the potential for malicious applications to cause problems for the STIS server by sending large number of requests, or by sending oversized requests in XML format.

Since some user-layer applications will communicate over wireless links with the STIS server there is a danger the travel information could be "snooped", and messages impersonated. This security, although largely the responsibility of the user-layer application, could be prevented by implementing some content hash checking, random challenges of the end-user, or using the WPA security protocol for the wireless link. The HTTP connection between the client and server (STIS servlet) could be upgraded easily to use HTTP/S further improving the security of the system as a whole.

4.4.6 Insecure Properties Files

A major vulnerability of the system lies with the fact that the Spatial API requires access to a number of plain text properties files to initialise the connection to the spatial database. The JDBC drive, URL address of the database, and the username/password are all stored in plain view on the STIS server, and could reveal the database connection details to malicious users, or indicate JDBC drivers with known security problems. These properties files would only become apparent if a malicious user had access to the STIS server, and this scenario is not thought likely in a well protected system.

4.5 Implementation Results

The system is only visible through the output it produces, rather than the internal calculations it performs, and since the output consists of relatively large XML file the performance of the system as a whole is best established using the presentation layer graphical front ends.

The project demonstration, on the 25th August 2006, used both the web-based STIS servlet web-interface, and the Map Viewer application, to showcase the data retrieval and route calculation aspects of the project. The results of the routing calculation could be send overlaid directly on a street-map of Dublin, and verified visually.

The sum total of the implementation, is therefore condensed to a single graphic image of the route on a map, and may not properly reflect the level of work that goes on in the background to produce a "simple" image.

4.5.1 Map Viewer application

The Map Viewer application allows users to view all the spatial data in the cache/spatial database, as well as make route requests, and see the responses overlaid on the map of Dublin.

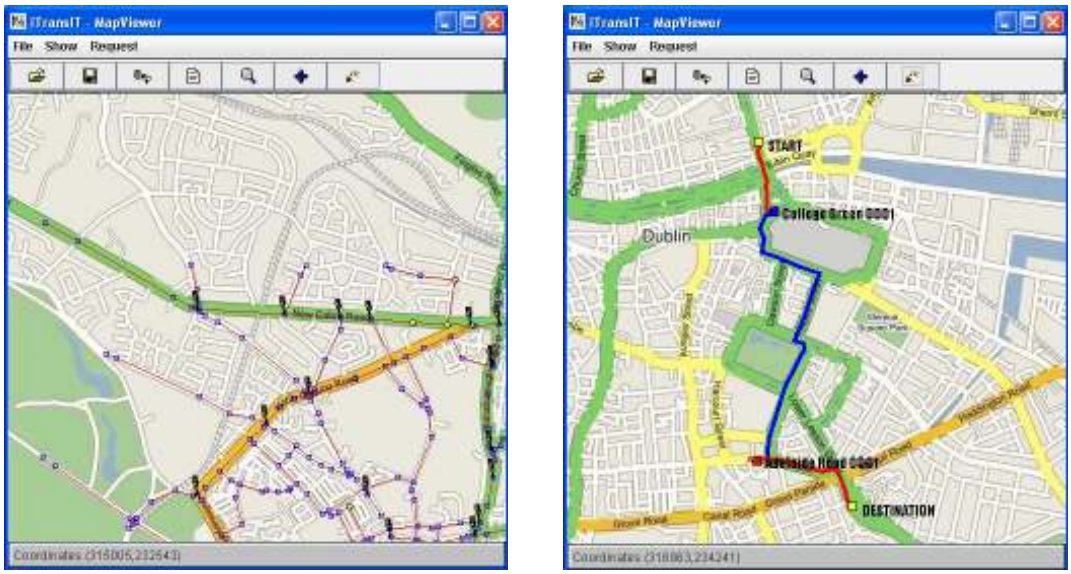

Figure 25 - The Map Viewer application, displaying various spatial data (left) and displaying a walking/bus multimodal journey.

In addition to graphically displaying the spatial data, and journey routes, the Map Viewer provides functionality to scroll and zoom the map, as well as the ability to save routes to disc be re-opened and displayed later. For convenience, colours are used to distinguish various modes of travel along a particular route. Red designates road routes, while blue and magenta describe bus and Luas routes respectively.

Colours are also used to display the traffic congestion along various routes through the city, red being the most congested roads, yellow moderate congestion and green light congestion.

4.5.2 STIS Servlet web-service

The STIS web-service is a servlet-enabled web application which allows users with a web-browser to access the STIS Server, and request a journey route. There is no requirement placed on the web-browser other than it must be capable of displaying jpeg images, and supports HTML forms.

The user initially specifies a URL to the web-service, which brings up the first "welcome" screen, with a number of textboxes allowing a user to request start, destination and waypoint lists, as well as specifying the preferred mode of travel. Entering text (such as a street-name), coordinates of junction ID values, and clicking the "Refine Route Parameters" button, will bring up the journey refinement screen. This screen allows users to pick the desired start/destination/waypoint from a list of available options, and once satisfied, can proceed by clicking on the "Calculate Route" button.

Figure 26 - The initial query web-page (left), and the journey refinement page (right), both as displayed within a web-browser.

This refinement process is required, to allow the requesting user opportunity to polish their journey request before committing to a route. Again, as was described in section 3.1 of this document, the refinement operation is limited to the number of street-names present in the spatial database. Often the system will not provide a list of journey options based on a user's input, due simply to a lack of available data. The system supports the refinement of user input based on Irish grid coordinates, or junction ID. In the case of spatial/geographic refinement, the system calculates the nearest junction(s) to a provided coordinate, and then lists the options available to the user.

The system will be able to cope with the removal of various stop-words from the user's input (e.g. "street", "road" etc.) however there was not enough time to implement methods to deal with incorrect user input (e.g. "Pboro Road" in place of "Phibsboro Road"). This functionality could have been added to the system given more time, and, it is felt, would have significantly improved the user-experience of the system as a whole.

When a user has finished refining the options available, the "Calculate Route" button forwards the user's selections (via HTTP POST) to the STIS Servlet, which in turn instantiates a Route Request object, calls the "toXML" method on this object, and sends the resulting string over the a socket connection to the STIS Server. The STIS Server spawns a new STIS Server Thread to deal with the request, re-assembles the Route Request object from the XML and uses this as an input to the STIS Routing

Engine. The STIS Routing Engine produces a Route Response object, which is sent back to the STIS Server Thread, converted to an XML string, and sent back to the STIS Servlet. The STIS Servlet re-assembles the Route Response object from the XML, and provides this as input to the Map Generator class, which produces and saves the image of the route response to disc. The path to this image is provided back to the STIS servlet which builds a HTML response (using the HTML Builder class), finally responding to the user's request with a HTML message sent over HTTP. The path to the map image is provided in the body to this request, and is stored in a directory on the web-server as long as the servlet exists. When the servlet exits, its destroy method deletes all files generated by the servlet during its lifetime, thus keeping the disc space used by the servlet to a minimum.

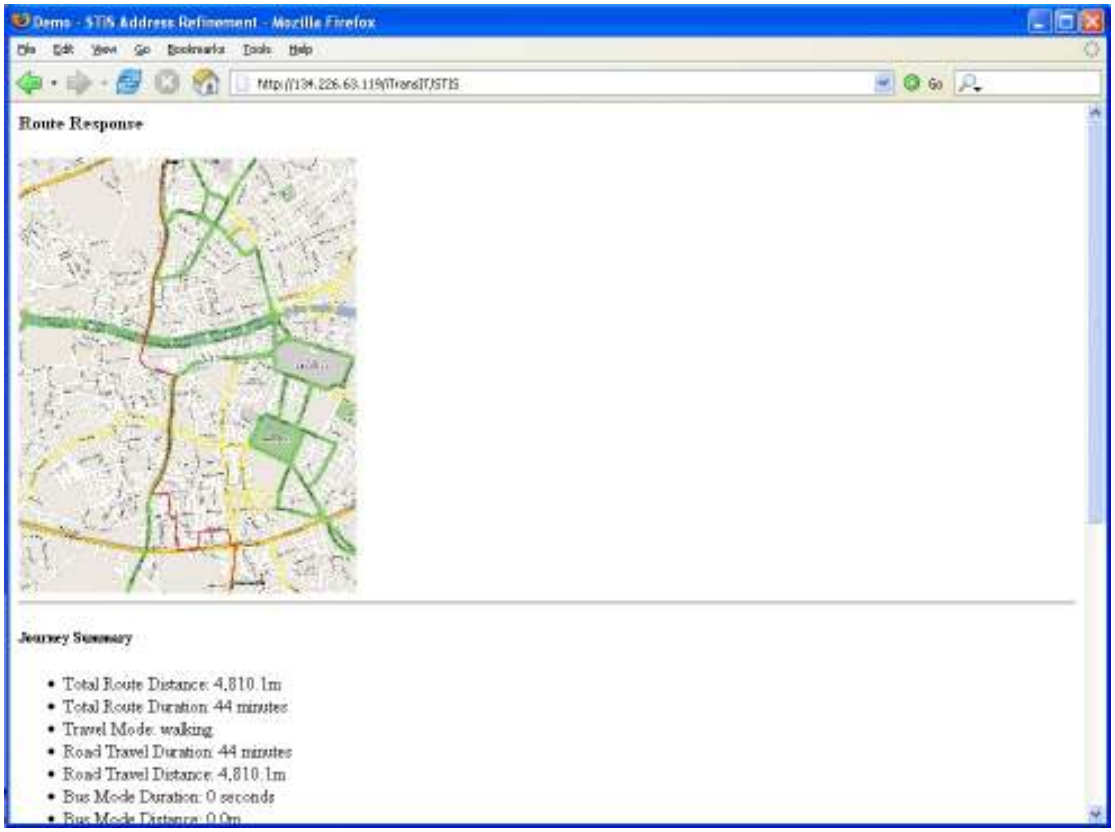

Figure 27 - STIS Servlet response, as shown displayed in a web-browser

The HTML produced by the STIS Servlet was tested on multiple web-browsers, and included some java scripting elements to allow multiple waypoints to be specified dynamically by the user.

5 Evaluation

The evaluation scenarios for this project changed somewhat when the project scope was extended. Previously the primary focus of the project proposal was to develop a multi-modal routing capability, with a secondary goal of integrating this routing functionality with the underlying spatial API to access the data in the iTransIT spatial database [29]. These goals were extended to incorporate the correct display of the spatial data, and the provision of a graphically correct route map outlining the journey plan, along with the journey summary.

The final evaluation scenarios outlined in this document were created during the latter stages of the system design process. Essentially the system is evaluated on a number of criteria, such as:

- Routing correctness and applicability.
- Use of the spatial API for information retrieval.
- Utilisation of multiple transportation modes in routing.
- STIS response times.
- Device independence.
- Presentation of route information.

The system was designed to operate in as close a manner as possible with a contemporary routing or mapping web-service. Typically responses are handled in a number of seconds, and multiple users can connect to the service in parallel. The hardware for the STIS system would not be at the same level as a commercial web-service, however the design of the system reflected the hope that the response times and user acceptance would be of a similar standard.

5.1 System Evaluation

5.1.1 Evaluation of the Spatial API

The Spatial API was a Java API developed in a previous project [17], and allows users to access travel-related information from a database. This database is configured to use spatial information, such as geographic coordinates, as a feature of the retrieval operation.

In the early stages of the implementation there was an open question about just what advantages the spatial API (S-API) gave in terms of information retrieval over a direct JDBC connection to the database. The JDBC/SQL direct query has the benefits of a finer control over the scope of the particular search operation, but loses out on the level of abstraction provided by the S-API. Certain features of the S-API, such as the listing of junctions/bus stops inside a geographic boundary, would be a useful feature more difficult to express in a direct SQL query.

The S-API however proved to have some quite substantial drawbacks, principally the speed and reliability of relatively simple retrieval operations. As an example a test class was developed using both the S-API and an equivalent JDBC/SQL query. The S-API was timed retrieving all 1306 junction identifiers and associated junction coordinates from the database in approximately 13-14 seconds. The equivalent "direct" JDBC/SQL retrieval operation to the same database for the same information was measured taking on the order of 1-2 seconds. Therefore there is roughly a ten-fold increase in retrieval times using the S-API for bulk retrieval operations. The system was checked to find if there were any mitigating factors for this slow performance. The retrieval time was achieved using the locally installed copy of the iTransIT database, when the CPU load was less than 5% and when the memory usage was also at a minimum. It was suspected the slow performance of the spatial API was due to the use of the SpringFrameWork JDBC libraries to connect to the database, and execute SQL queries.

More worryingly for the performance of the S-API, it would occasionally throw exceptions if a bulk read of data was performed, due to the constant setting up and tearing down of sockets to connect to the database. This was an issue more with the

SpringFrameWork libraries than the S-API itself, but could be easily rectified by changing the S-API to use a better JDBC library.

In addition to performance issues, there were some limitations to the scope of the API itself. Currently the spatial API can retrieve objects within a user-definable spatial area. What is not present in the database, and what would be very useful, would be the extension of this functionality to allow users to retrieve objects by specifying a minimum or maximum distance from a fixed point.

Originally, when the spatial API was first implemented, the spatial database did not include any street name information. When type of lookup operation was required later for the STIS Server, there was limited support for retrieving street-name values, and no functionality to return multiple possible matches. For example the SQL query,

```
SELECT * FROM TABLENAME WHERE NAME LIKE "A%ROAD";
```

would return a list of names (if they existed in the database) beginning with the letter 'A' and ending with the text 'ROAD'. This simple SQL lookup could not be performed via the Spatial API, and as a consequence any street-name matching was performed on the server side rather than the database side.

5.1.2 Route Retrieval Latency

An important aspect of the overall system design was that the calculation of a route response, should not take more than several seconds, in order to provide a good user-experience of the system. This requirement tailored the overall design, and ruled out using certain exhaustive (and time-consuming) routing algorithms, in favour of dynamic route calculation heuristic-driven algorithms. In addition, to minimise the CPU load, and keep the memory footprint small (to allow multiple concurrent users) features such as constructing multiple parallel routes, evaluating them and returning the most appropriate, were ruled out.

By analysing a relatively small number of route responses, it was found that the outputs from the STIS system had a delay directly proportion number of links that

have been included in the route response. Typically there was a slight increase in the latency of the initial route response, due to the initialisation and setup of the socket connection between the STIS servlet/socket client and the STIS server. The response latency gives the average response time being approximately 1.86ms per route-link.

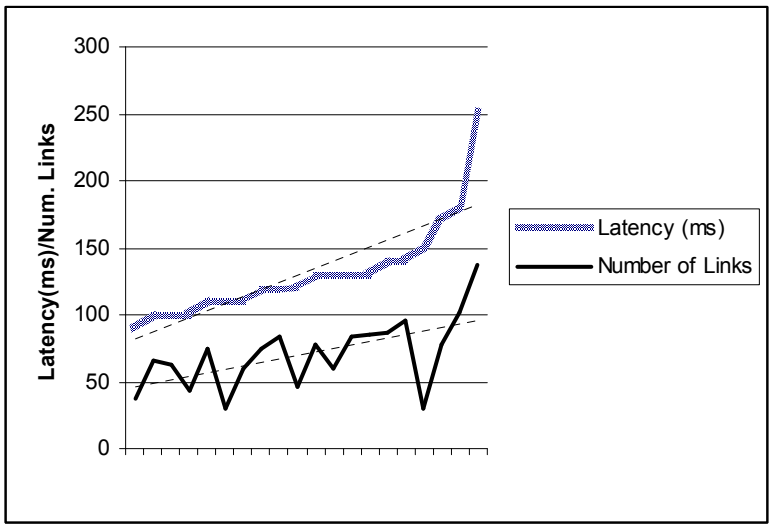

Figure 28 - The response delay (latency) compared to the number of links in the route.

The quickest route returned from the sample of 20 route requests made, was 90ms, for a Luas route between Luas Stops on the same line. The route response with the highest latency was 251ms, for a multi-modal Luas route with 138 links in total. The graph above (Figure 28) shows the latency more or less proportional to the number of links in the resulting route.

The variations in latency versus the number of links are caused by the various transport types. For example the array used to hold the junction data is far larger than the same array for the (limited) bus and Luas data available to the STIS system. The number of potential candidates from one Luas stop to the next is small (i.e. one stop either side), whereas for junctions there could be four or more candidates when planning a route from junction to junction. The differences in node density between the graph of the road junctions, and the Bus/Luas networks means that a road route will on average require more computation to get from start to destination, and hence a higher overall latency in servicing the response. The slight increase in latency as the

number of route links grows is due in most part to the size of the XML string returned describing the longer route.

5.2 Route Evaluation

5.2.1 Evaluating Multi-modal Routes

One of the major requirements for the system was to provide a multi-modal route though Dublin. This goal was, on the whole, accomplished, since the final implementation of the STIS software will return to a multi-modal route using any of five separate modes of transport.

Figure 29 - Various routes between Pearse St. and Rathmines Road. Walking route (left), Luas route (middle), Bus route (right).

The evaluation of multi-modal journeys proves a more difficult problem. The issue is further complicated by the sparse route data for the Luas and Dublin Bus networks in the spatial database. A route was selected which could be used to demonstrate Luas and Bus routes travelling in the same direction.

The specific route for each mode of transport is determined by a large number of factors, such as the one-way street system in the case of vehicles and cyclists, and the location of stops in the case of the Luas and Bus networks. In addition multi-modal routes can be connected together where the start and end points are not serviced by the same mode of transport.

Transport Mode	*Start*	*Destination*	*Mode Duration*	*Total Distance*
Walking	Pearse Street	Rathmines Road	26 minutes	2,823m
Cycling	Pearse Street	Rathmines Road	11 minutes	3,399m
Driving	Pearse Street	Rathmines Road	8 minutes	3,399m
Walking/Luas	Pearse Street	Rathmines Road	14mins/4mins	3,507m
Walking/Bus	Pearse Street	Rathmines Road	10mins/7mins	3,327m

The table above describes five routes each using one or more of the supported means of transport. The Luas and Bus routes, which can be observed in Figure 29, utilise some walking components in the overall route. The disparity in distances between the various routes taken is explained by the fact that each route deviates slightly from the other.

5.3 Evaluation Summary

The system was found to perform up to the initial expectation as was outlined during the design and implementation phase of the project. The high level goal of the system, providing users with a multi-modal travel plan through Dublin, was achieved, as was the extra goal of providing a means to display this route graphically.

The basic routing functionality incorporated into the system, whilst not guaranteeing the shortest path, performs much better than any exhaustive search algorithm capable of calculating the shortest path. The route response returned will be, for most routes, the shortest path between those points. The design decision taken at the beginning of the project gave a preference this type of dynamic routing algorithm capable of dealing with large search spaces.

5.3.1 Evaluation Elements

Task	*Description*	*Status*	*Comments*
1.	Integrate the STIS system with the Spatial-API to provide route planning information about the different travel data sources.	Done	The Spatial API is used to provide the spatial data for the STIS system.
2.	Provide a caching mechanism to store the information retrieved from the spatial database.	Done	
3.	Develop an XML interface to handle user requests.	Done	
4.	Develop XML schemas for request/response travel data.	Done	All information passed to the STIS is encapsulated in XML.

5	Provide road routing functionality (driving/cycling/walking) using the Dublin street network.	Done	Road routes can be found using the system, respecting the one-way street system.
6.	Provide bus routing functionality.	Done	Bus routing functionality is available, however the routing is limited to the sparse data set available in the spatial database.
7.	Provide Luas routing functionality.	Done	Both Luas lines available, and routes are possible between different lines. Only 10 Luas stops listed in the spatial database.
8.	Provide multi-modal routing functionality.	Done	The system will allow a user to construct a multi-modal route, using the various modes of transport supported by the system.
9.	Provide route description summary.	Done	Total distance, and duration, along with the distance/duration of each mode of transport used it listed. The system also provides graphical route descriptions, in conjunction with the presentation layer applications.
10.	Provide street-name route description.	Partially Complete	480 roads out of 2800 does not facilitate a street-by-street route description, however the street-names where encountered are listed in the response XML.
11.	Allow for user input of imprecise information, and journey refinement.	Done	The system will respond to incorrect or imprecise user inputs with appropriate options.
12.	Allow spatial coordinates to be provided as input.	Partially Complete	OSI coordinates can be provided by the user as input, however direction of travel using polar coordinates is not supported.
13.	System response times within typical web-service expectations	Done	The typical average response time is on the order of 150-200ms locally.
14.	System is scalable.	Done	The system supports multiple clients, and can be hosted from

			multiple servers, geographically co-located or separated.
15.	System provides capabilities for incorporation of new legacy data sources.	Partially Complete	The XML interface will support any number of new travel data sources. Some changes are required in the routing functionality.
16.	System guarantees shortest overall route.	Not supported	The system provides a reasonably short route, but does not guarantee the shortest path.
17.	Parallel computation of alternative routes.	Not supported	The system calculates only a single route at a time.
18.	Provision of multiple waypoint routing.	Done	The system can calculate a route using a large number of intermediate waypoints.
19.	Provide timetable information	Not supported.	The system was limited by the small amount of timetable information available in the spatial database.

6 Conclusion

The Smart Traveller Information System revealed a number of findings which were not immediately apparent at the beginning of the project. Foremost amongst these was the complexity involved in implementing a dynamic, efficient and correct multi-modal routing algorithm, and the challenges posed in creating a means of displaying route information correctly and clearly for the user.

The contribution of this project was threefold, firstly to demonstrate that multi-modal routing was possible using only the information present in the iTransIT spatial database, secondly to exhibit how the existing spatial API could be used to retrieve and update this data, and lastly to provide a means to display this journey planning functionality in a graphical form.

The system implementation proved that multi-modal routes could be calculated, using the spatial API to retrieve the underlying travel data from the spatial database. In addition the two GUI interfaces developed for this project enabled the graphical display of these multi-mode routes, as well as allowing users to formulate, and refine route requests.

The goals outlined at the start of the project were largely accomplished, and the basic multimodal routing functionality developed can quite easily be extended to produce better routes and journey plans, over many different modes of transportation. Due to the way the routing algorithm works, the transport networks (road/bus/Luas) can be expanded without adding any delay to the route calculation. Exhaustive search algorithms would suffer considerably, since the time it takes to calculate a route is directly proportional to the number of links present in the network as a whole.

The performance of the system, in terms of response time and availability, was of secondary importance, to the provision of route planning functionality. However, due to the design of the system as a whole, it was found that the availability of the STIS server, and the response time for requests to this server, compared favourably to existing web-based journey planning services.

6.1 Future Work

This section describes areas in which future work could be directed, to improve and expand upon the work done during this project.

6.1.1 Additional Routing Functionality

The STIS system implemented a basic multi-modal route planning service. There exist many opportunities to expand the system to both improve the route planning service as it exists, potentially adding new routing algorithms, or improving the existing algorithm. Currently the heuristic used to find routes through Dublin does not guarantee that the route returned is the shortest, nor the quickest. This was due to the requirement that all routing should be dynamic, and return a result in a reasonable time. Exhaustive search algorithms, ruled out due to their inability to cope well with large networks, could be useful if the search space was reduced by pre-selecting a certain area.

6.1.2 Adding more information to the database

The principal limitation of the system was the amount, and type, of data present in the iTransIT spatial database. During the course of the project implementation, various additions to the data set were required in order to implement functions in the software, namely the addition of street-names to the database to assist in journey waypoint refinement.

The STIS system was also restricted to some extent by the lack of more data in the iTransIT spatial database. Overall the system would be improved by the addition of more data, especially extra transportation links such as the DART system, Bus Eireann, and taxi information. During the implementation of the project, the spatial database contained,

- *10 Luas Stops from potential 30 or more.*
- *15 Bus Stops from several hundred in Dublin*
- *2 Bus Routes over a limited distance.*

Since the routing functionality could only work with the information present in the database, it was felt that the routes produced by the system would have been greatly improved by the supplementing the database with more data elements. The bus routing functionality especially, would have significantly benefited from more bus stops and bus routes in the database. The Luas information could likewise be added to, to improve the STIS routing functionality.

The traffic congestion information, which was produced by a simulator and inserted in the database, was limited to only 51 points of information, from a potential pool of 1300 junctions. A useful extension to the project would be to produce a more detailed list of traffic congestion information for Dublin, or better yet, connect to a real-time traffic information system.

Some other information, which was lacking from the underlying data, could be added at a later date. This included information regarding the location of pedestrian areas in Dublin, and larger area names in general (e.g. Rathmines, City Centre etc.).

6.1.3 Integrating System with Mobile Location Services

At the moment the capability exists for standard GSM/GPRS, as well as 3G handsets, to be geographically positioned using the radio signal between the handset and the base-station to describe a "location area" in which the handset is located. In addition, some handset manufacturers are providing GPS support within some newer mobile handsets to refine the location area to a radius of several meters.

There is the possibility of quite quickly opening up the STIS system to be accessed via a modified presentation layer which takes handset location information as an input to calculating a route. An example of this type of service would include a handset-based tourist guide, automatically directing a mobile user around a city's landmarks in a user-specified language. This type of service is already present in various Asian markets, and was recently introduced to the UK to support mobile navigate services, using GPS positioning [30].

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