STIS: Smart Travel Planning Across Multiple Modes of Transportation

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Abstract— **Travellers require information on individual transport systems when planning a journey. Many transport-rich urban environments contain numerous underlying transport infrastructures, offering a traveller various ways to complete the journey. This paper presents the Smart Traveller Information Service, a system designed to offer travellers an easy to use and efficient means of planning journeys in an otherwise complex multi-modal transport environment. The Smart Traveller Information Service bridges the coordination gap between the available transport systems (both public and private), and hides the complexity of the travel planning process from the user. This allows travellers to construct detailed journey plans without concerning themselves with the often heterogeneous and disjoint nature of the available transport facilities.**

I. INTRODUCTION

Travel information services of a basic type have existed since the first paper-based train timetables. Today's public transport companies largely maintain this route and timetable approach, albeit often in an electronic form. Travellers planning a journey in a well-provisioned transport environment can be presented with a vast choice of potential destinations, modes of transport and other assorted travel options. An (unfamiliar) traveller may experience difficulty in planning a route, due to the scope and size of available transport infrastructures, and the complexity of finding a given route for each mode of transport.

Routing and scheduling problems faced by travellers in modern urban environments stem from the intricacies of the underlying transport networks, especially the selection of an optimal route from a multitude of available travel options. Planning a journey using one or more modes of transport becomes more difficult when individual transport networks are large (and complex). Any coordination gap between the various transport networks can expose travellers to the unenviable task of searching across each individual mode of transport, over multiple routes, timetables and other travel options, in order to devise a complete journey plan. The ultimate goal of travel information systems is to assist users with the selection and creation of an end-to-end travel plan, whilst hiding the underlying complexity of the route planning process. Travel preferences, supplied by the user, form the basis for any travel plans generated. However, many basic travel information services restrict users to a single mode of transport, which in turn limits the options available, and the usefulness of the service as a whole. Travellers may only gain the maximum advantage when their travel preferences are the main determining factor in the planning of a journey. Any latent systemic bias towards a single route, operating company or mode of transport should be avoided when producing journey plans for the user.

The Smart Traveller Information Service (STIS) provides users with a means of planning multi-modal journeys, using the user preferences as the sole basis for creating journey plans. The service coordinates between multiple transport networks to enable end-to-end route planning using various modes of transport (where required). STIS aims to construct complex multi-modal journeys in an efficient manner, responding to users with detailed, device-independent travel information. Users can avail of the address refinement functionality in STIS to correct any partial address information, as well as performing address lookups on spatial coordinates. The resulting travel plan returned to the user includes a complete route description, as well as a summary of the journey listed according to the mode of transport.

Building upon the functionality available in the iTransIT framework [1], STIS provides an easy to use, efficient travel planning service, capable of integrating with many heterogeneous travel data sources. The iTransIT framework implements the spatial programming model [2], that enables pervasive transport services such as STIS, and provides a focus for the integration of distributed transport information. A Spatial Application Programming Interface (SAPI) allows the STIS service to access the transport data in a common format, regardless of the type of transport data being requested.

STIS supports user requests and responses, using a device-independent XML format, that permits travel information to be tailored by each user device according to its own limitations - an important feature on mobile devices with restricted resources. Existing mobile and web-based applications can quickly add the STIS route planning functionality, by supporting this XML interface.

The remainder of this paper is structured as follows, section II presents related work, section III describes the STIS system in detail, section IV evaluates the STIS system, and section V presents the author's conclusions.

II. RELATED WORK

Many modern public transport companies provide a web-based travel information service. A search of the internet for "public transport travel planning" reveals over five million relevant web pages [3]. These travel services may be classified into one of three broad types - single-mode route/timetable lookup services, single-mode user-centric travel services, and multi-mode travel services.

Route/timetable lookup services are frequently associated with public transport companies that have a large existing corpus of route and timetable data. Information is made available to users through a simple search interface based on lookups of a stop/station name or route number. Examples of this type of travel information service include offerings from bus [5], rail [6] and tram [7] operators, operating over a single transport infrastructure. Journeys involving travel outside of the operator's network are not supported, nor are there any provisions for linking multiple networks into a coherent travel plan.

Single-mode user-centric travel services produce unique travel plans, based on user travel preferences rather than any pre-existing routes. In contrast to route/timetable lookup services that perform no actual routing calculations, all routes requested from a user-centric travel service are calculated dynamically. This type of service generally offers route planning exclusively over the road network, often omitting any integration with public transport services. Service providers include the AA journey planning service [8], as well as some internet map providers [10] and other road-based routing services [9]. Vehicle-centric route planning services, being tied in with the road network, cannot generally bridge the coordination gap between public and private transport. This deficiency restricts traveller choice, and potentially leads to even greater traffic congestion on the roads.

Multi-modal travel services provide users with travel plans independent of any route, timetable or travel mode restrictions. Users can plan an end-to-end journey using multiple modes of transport, basing the resulting journey plans on user preferences rather than restrictions due to infrastructure. In well-developed urban centers, some travel services exist that highlight the potential offered by multi-modal travel services. For instance, the Transport for London (TfL) travel service [4] provides users with a combined bus/metro/rail journey planner capable of generating routes combining all three public transport options. The service however neglects driver, cyclist and pedestrian routes, providing only public transport options. As a result, complete end-to-end journey plans are available only between listed bus/metro stops. The STIS service, in contrast, enhances the functionality available in these types of multi-modal travel services by including various modes of travel (both public and private), traffic congestion information, address refinement and support for spatial queries. Additionally, the STIS service provides travel information in a format capable of being displayed on various mobile devices. The functionality provided by the iTransIT framework is leveraged by STIS to allow for scalability, both in terms of adding new modes of transport, as well as enhancing the information on existing modes.

III. ITRANSIT FRAMEWORK

As illustrated in *Fig. 1*, the iTransIT framework arranges legacy systems, iTransIT systems, and context-aware, end-user applications into three tiers. These tiers define the relationships between systems and applications, and provide a scalable approach for integrating transport data sources, in that individual components can be added to a specific tier without direct consequences to the components in the remaining tiers.

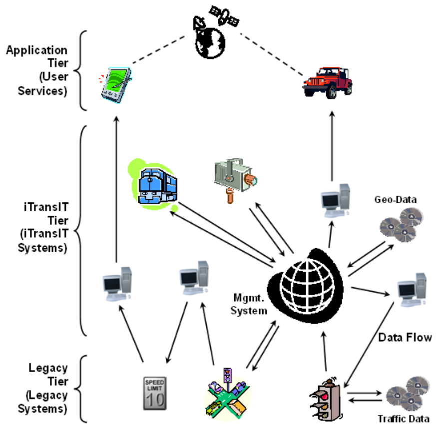

Fig. 1. The iTransIT Framework

A. Tiered Architecture

The iTransIT system architecture supports the integration of legacy systems, and supports future systems that conform to the overall architecture and data-layer.

The purpose of the iTransIT tier within the overall framework is to integrate transport systems that model spatial information and implement the Spatial Application Programming Interface (SAPI) . Therefore, this tier consists of a federation of transport systems that implement the spatial data-layer. The data-layer is distributed across these iTransIT systems, with each system implementing the subset of the overall layer that is relevant to its operation. iTransIT systems maintain their individual information, which is often gathered by sensors or provided to actuators, by populating the relevant part of the spatial data-layer. However, some of the information maintained in an iTransIT system-specific part of the data-layer may actually be provided by underlying legacy systems. Most significantly, traffic information captured in this tier is maintained with its primary context, and persistently stored data is geo-coded, typically by systems exploiting a database with spatial extensions.

The application tier includes pervasive value added services, such as STIS, that provide context-aware user access to travel information. These services use the distributed data-layer and the associated context to access information potentially provided by multiple systems. They may include a wide range of interactive (Internet-based) and embedded control services, ranging from the monitoring of live and historical traffic information to the display of road network maps.

B. *Common Spatial Data Layer*

The spatial data-layer, common to all iTransIT systems, is comprised of a set of potentially distributed sub-layers and represents the central component of these systems. Individual iTransIT systems implement one or more of these sub-layers (or parts of sub-layers) and maintain the static, dynamic, live, or historical traffic data available in that sub-layer. For example, a system might implement a sub-layer describing the current weather conditions, while another sub-layer capturing intersection-based traffic volumes might be maintained by a different system.

IV. SMART TRAVELLER INFORMATION SERVICE

The STIS has been designed as a middleware platform, that enables users to create complex journey plans, using transport data provided by the iTransIT framework. STIS is located between a requesting user (typically using a mobile device), and a collection of heterogeneous transport data sources, that are made available through the iTransIT framework.

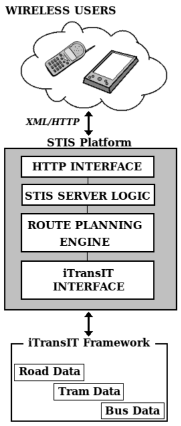

Fig. 2. The STIS architecture.

As shown in *Fig. 2* there are four core elements to the STIS service, a HTTP interface to communicate with users, a service-side control logic to manage requests, a routing engine to generate the journey details, and an interface for retrieving information from the iTransIT framework. The service is initiated by a user sending an XML request to the system. Once the user preferences have been verified, a route is calculated using data from the iTransIT framework, matching the preferences expressed in the user request. When an appropriate route is found an XML response is returned to the requesting user. The STIS Server Logic maintains information on user requests, and ensures that responses are forwarded to the correct user.

A. *Initiating the STIS service*

User requests are implemented typically within the context of a GUI-based travel planning application, either a web-based client, or a thin-client installed on a mobile device. Each type of application is expected to generate valid STIS XML requests, to parse STIS XML data and display the responses. This enables mobile devices with limited resources to display STIS data in a suitable format. Each STIS response contains information enabling a route to be reconstructed, and to be overlaid on a locally stored map. Where resources are limited, for example with legacy mobile devices, a text-based route summary may be extracted, instead of a graphical representation of the route. Both user requests and responses use HTTP to communicate with the STIS server. Each STIS request contains information on the device type, the preferred modes of travel, and at least two preliminary journey waypoints (i.e. the start and destination).

The initial journey waypoints are treated as preliminary data, in that they may be subject to refinement by the user at a later time. Users will often provide inaccurate or imprecise travel information. Spelling mistakes, non-existent streetnames and/or missing address suffixes (street/road/lane etc.), all lead to uncertainty in planning a route. Address refinement is used by STIS as a critical guard against these input errors, offering users a list of intended (corrected) locations to resolve any ambiguity.

Start:	Lower Abbey Street (324) Middle Abbey Street (781) Upper Abbey Street (791) Luas-Stop, Abbey St-inbound (76) Luas-Stop, Abbey St-outbound (91)
Waypoint(1):	Harcourt Street (287) Harcourt Road (292) Luas-Stop, Harcourt-outbound (90) Luas-Stop, Harcourt-inbound (92)
Destination:	Baggot Street Upper (523) Baggot Street Bridge (523) Baggot Street Lower (642)
Mode:	***cycling***

Fig. 3. Refining journey waypoints, using a list of potential corrected locations similar to the initial incorrect user input.

As shown in *Fig. 3*, this address refinement list can contain bus/tram stops, as well as street and place names. Address refinement may also be performed where a user enters plain spatial coordinates. Support for spatial coordinates allows users to input data from positioning devices (such as GPS devices), requesting travel information based on their current or projected location. The STIS platform verifies all journey waypoints before proceeding with the calculation of a route.

B. Retrieving Tranport Information

Transport information, such as bus stops, tram stops and road network junctions, are stored as spatial objects in the iTransIT framework. The SAPI provides the interface to request this spatially-encoded information, and can return one or more spatial objects. The iTransIT data model also maintains the logical links between adjacent elements in the transport data, thereby allowing for node-to-node route searches.

C. Generating Journey Routes

Each transport network is represented by a separate logical graph, with interconnections between the various transport networks placed at overlapping spatial locations. For example, each bus or tram stop has an associated road junction, allowing seamless multi-modal routing between road, bus and tram services. STIS views each transport network (e.g. bus, tram, road) as a two-dimensional directed graph, with the connections between nodes reflecting the linkages between adjoining road junctions, bus stops and tram stops. These two-dimensional graphs allow links to be traversed in one direction only, in order to maintain the correct flow through the transport network, for example in one-way streets. As each node in the graph has an associated spatial position, STIS can calculate distances between any two non-adjoining nodes.

The route calculation performed by the STIS platform uses a heuristic-driven shortest path algorithm, in which the search time is $O(n)$, where n is the number of links along the route. This algorithm is based on the A* algorithm [11] and modified to search across multiple overlapping graphs.

The routing strategy adopted by STIS follows the user-preferred modes of transport when planning a route. Where no direct route is found between the start and destination (using the preferred modes of transport), STIS finds a route with endpoints close to the start/destination. This partial route is then completed with pedestrian sub-routes, linking the start and destination in a complete end-to-end route. *Fig. 4* illustrates this process of linking together various partial routes to form a single end-to-end route plan.

Routing is achieved by successively selecting the next connected node in a particular graph which satisfies a number of criteria, namely that the node has not been previously visited, the node is connected to the current node, and the node represents the perceived shortest distance[1] to the final destination. Secondary criteria may also be considered, such as traffic congestion and road size (in the case of vehicles) [12], timetable issues (in the case of public transport), and one-way systems (in the case of vehicles and cyclists, but not pedestrians).

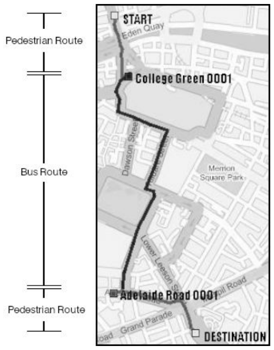

Fig. 4. An illustration of the sub-routes comprising a single multi-modal journey. Pedestrian sub-routes at the top and bottom are used to connect the bus route in the center, with the start and destination.

This routing algorithm minimizes the response time for a routing request, as the time it takes to calculate a route is proportional to the number of route elements, rather than the number of nodes in the graphs being searched (the search space). Whereas an exhaustive search would find the guaranteed shortest path, the time required to calculate this route would increase dramatically for each increment in the size of the underlying transport data [13]. A secondary benefit of this search algorithm is that the addition of any new modes of transport to the iTransIT framework is not expected to effect the performance, or the computational cost incurred by the STIS platform.

D. Route Selection & Response

The STIS routing algorithm initially considers the permissible modes of transport as specified by the user. Depending on the waypoints chosen by the user, it may or may not be possible to undertake the entire journey using the preferred mode of transport. A route is built up, using the preferred mode of transport as much as possible, interconnecting bus/tram/vehicle routes where needed by pedestrian sub-routes. Due to the limited routes provided by most public transport companies, travel between any two points using an existing route may be sub-optimal. All routes produced by the STIS routing algorithm are evaluated against a "direct" pedestrian route using the same waypoints. The estimated travel times and distances of the two routes are compared, and if a short pedestrian route is found with a substantially reduced travel time, then it selected as the optimal route. For example, a 2km bus journey will be deemed unnecessary by the STIS routing algorithm if the user is a 100m walk away from their stated destination.

Routes using multiple waypoints (i.e. more than two) are evaluated as individual sub-routes, and combined into a single overall route before being returned to the user. Connections between the transport networks are created as pedestrian sub-routes, allowing a complete end-to-end route plan to be returned to the user regardless of the limitations of the transport networks. When STIS selects the optimal

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[1] Since the algorithm uses a non-exhaustive search, the next node selected by the routing algorithm cannot guarantee that it will lead to the shortest path to the final destination.

route, a link-by-link route plan is constructed, containing directional information and the spatial description of each link in the route. This enables the client device to independently reconstruct the route from the information contained in the XML response. The STIS XML response also gives a route summary, listing the the total distance and estimated travel time, according to each mode of transport.

V. EVALUATION

The goals of the Smart Traveller Information Service are to provide users with an easy to use and efficient means of planning user-centric multi-modal journeys, bridging the coordination gap between the various modes of transport. For evaluation purposes, a prototype STIS has been developed in conjunction with two simple Graphical User Interface (GUI) demonstration applications - a stand-alone client-side application, and a service-side web-based GUI. These applications allow users to submit STIS travel requests, refine their travel options, and visually inspect the journey plans returned by the service. This latter aspect is crucial, as multi-modal journeys are best evaluated by comparing the resulting multi-modal route with the original travel preferences. *Fig. 5* illustrates the view presented to the user by the stand-alone GUI client, and shows road network data (featuring traffic light information) available in the iTransIT framework, overlaid on a street-map.

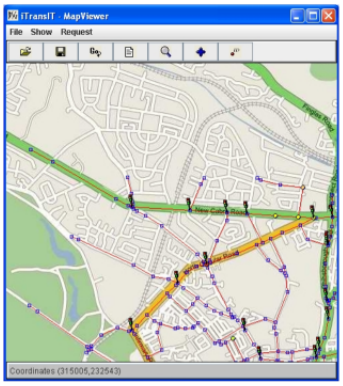

Fig. 5. GUI "MapViewer" Application for STIS, showing road routes, traffic lights and traffic congestion.

Mobile devices can use either the Java-based client-side application, or for more restricted devices, the web-based service-side (Servlet) application. The differences between the two applications are small, with the client-side device allowing users to interact with the iTransIT data in greater depth, and display road congestion information, traffic light position, and bus/tram stop locations. Both applications interface in the same way with the STIS platform, and display STIS travel information overlaid on a street-map.

The iTransIT framework provides the STIS prototype with transport data, allowing STIS in turn to support five distinct modes of transport - walking, cycling, driving, bus and tram. This iTransIT data contains tram and bus routes serving Dublin city center, as well as data for the road network (with traffic congestion levels) within the Dublin metropolitan area.

Two evaluation scenarios are presented here - an assessment of the multi-modal aspects of the STIS platform, and an appraisal of the efficiency of the travel planning (route calculation) process itself. These scenarios demonstrate that STIS enables complex multi-modal journey planning, and provides an efficient, easy to use service to users.

A. Scenario 1: Evaluating STIS Multi-Modal Journey Planning

To evaluate the multi-modal routing aspects of the STIS platform, three separate requests were submitted (via the client-side GUI application). Each request uses the same start and destination points, but different preferred modes of transport. The requests are encoded as XML and submitted to the STIS with the response being displayed as a route-map using the GUI application. The three routes produced by the STIS can be seen in *Fig. 6*.

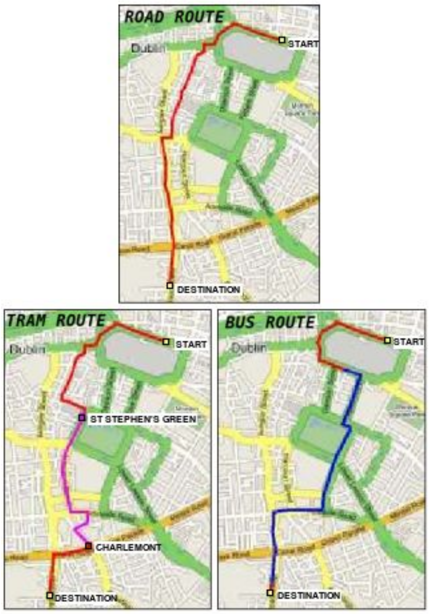

Fig. 6. Multi-modal journeys produced by STIS, and displayed using the stand-alone GUI client. All routes have identical start and destination points, but differ in the preferred modes of transport used when planning each route.

The image at the top of *Fig. 6* shows the STIS-generated travel plan for a driver of a vehicle in central Dublin. This route obeys the one-way street system, routing the driver from the starting point, at the top of the image, to the destination point at the bottom. A single mode of transport (vehicle transport) is used throughout the whole of this journey.

The image on the lower left shows a tram-based route between the same start and destination points. Specifically, this image shows a multi-modal pedestrian-tram-pedestrian route, as the end-points are reached by pedestrian sub-routes as in *Fig. 4*. The only difference between the initial vehicle-based request and this route is the selection of the tram as the preferred mode of transport.

The image on the lower right illustrates the STIS route response using bus and pedestrian modes of travel. Both the tram-based route (left) and the bus route (right-hand image) incorporate multiple modes of travel into the journey in that they both contain pedestrian sub-routes.

A comparison between the three routes shows subtle differences in the route response, resulting from the changes in the preferred modes of travel within each STIS request. Omitted from *Fig. 6* is the route summary provided by each STIS response, listing the distance, estimated duration, and route breakdown according to the mode of travel.

B. Scenario 2: Evaluating the Performance of the STIS Platform

The previous evaluation scenario demonstrates functional correctness of the STIS travel planning functionality, producing routes that reflect the user's travel preferences. In contrast, Scenario 2 evaluates the non-functional performance aspects of the STIS platform, such as the response latency of the STIS platform for variously-sized STIS responses (see *Fig. 7*).

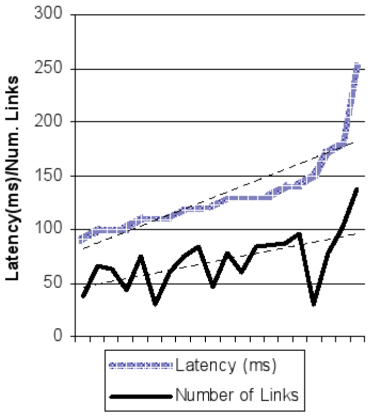

Fig. 7. Comparing STIS response latency with the no. of links in each route.

As this implementation of the STIS platform is a proof-of-concept, rather than an enterprise-level software release, the non-functional performance of the system is important, but not critical. User experience and functional correctness were considered slightly higher priorities, however both are directly affected by the non-functional behaviour of the platform as a whole. Both the STIS routing functionality, and the iTransIT framework have been designed for scalability - whereby the system can transparently accommodate increases in the scope of existing information, and new modes of transport can be added.

Measurements of the STIS response time, using various routes and travel preferences, demonstrate the response time to be proportional to the number of links in a route response (see *Fig. 7*). The routing algorithm used by the service is designed to complete in $O(n)$ time, requiring the response time to be linearly proportional to the number of links in the route (STIS response). From the measurements collected, the fastest response, a tram route of 20 links, was returned in 90ms. The highest response time was 251ms, observed for a multi-modal pedestrian/tram route of 138 links. Each individual link in the route adds approximately 100 bytes to the overall route response, resulting in longer transmission times (and increased latency) as the response message grows. In addition, differences in the size of the bus/tram/road data sets result in different retrieval times from the iTransIT framework, leading to a slightly longer latencies for calculating road routes.

VI. CONCLUSIONS

The Smart Traveller Information Service provides users with an efficient and simple way to create a complex journey plan, using multiple modes of transport along a route. This support for multi-mode transport in a scalable, expandable manner - allows new modes of transport to be seamlessly added to the underlying iTransIT framework. The STIS interface enables clients to easily generate travel requests and receive relevant journey information, tailoring this information for display according to the available device resources.

VII. ACKNOWLEDGEMENTS

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