THE MANY USES OF GTFS DATA – OPENING THE DOOR TO TRANSIT AND MULTIMODAL APPLICATIONS

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Abstract

The General Transit Feed Specification, or GTFS, has become the most popular world-wide data format to describe fixed-route transit services. Many transit agencies have created and published GTFS data with the primary purpose being integration with Google Maps. However, GTFS data can power many other different types of transit and multimodal software applications, including multimodal trip planning, timetable creation, mobile apps, visualization, accessibility, analysis tools for planning, real-time information, and interactive voice response (IVR). This paper provides an overview of the many opportunities available for transit and intermodal agencies to leverage open GTFS data and provide many new types of information services to the public or their internal operations with little to no cost to the agency. For transit agencies without open data, this paper will inform decisions on prioritizing and justifying investments in open data initiatives. For agencies that already provide open access to GTFS data, this paper will assist the agency in maximizing their investment in GTFS data by providing resources on how to access many new types of applications. Departments of Transportation, Metropolitan Planning Organizations, and other intermodal agencies will also benefit from this paper by learning the state of the art in transit information dissemination, which can power new state-of-the-art intermodal applications. This paper also provides a summary of industry best-practices that an agency can follow when deciding to create and share an open GTFS data feed to maximize exposure to new applications.

Keywords: public transportation, intermodal, data, GTFS, information systems, mobile, trip planning, analysis, software, applications

INTRODUCTION

Accurate and up-to-date data is important to any information system. To create an effective traveler information system that includes public transportation, a description of the routes, stops, and schedules that represent transit service is required. However, that data is not always easy to create.

TriMet in Portland, Oregon, along with Google, was one of the first public agencies to try and tackle the problem of online transit trip planners through the use of open datasets that are shared with the general public [1]. TriMet worked with Google to format their transit data into an easily maintainable and consumable format that could be imported into Google Maps. This transit data format became known as the Google Transit Feed Specification (GTFS) [2]. In 2005, this trip planning service was launched as Google Transit [1].

After a successful launch with TriMet, Google Transit offered their trip planner service for free to any agency that formatted and maintained their data in the GTFS format. In 2006, five more agencies were added. Google Transit's success continued as more and more agencies wanted access to a free trip planner, and were willing to put their data into the GTFS format to get it.

Since its creation in 2005, GTFS has become the most popularly-used data format to describe fixed-route transit services in the world. Many agencies have decided to share their GTFS data openly with the public, while others choose to restrict access only to select partners (e.g., Google Maps). There are an estimated 261 transit agencies worldwide, including 227 transit agencies in the U.S., that share their GTFS data openly with the general public [3]. Google states that their Google Transit service is offered to around 500 cities around the world [4]. Therefore, the total number of GTFS feeds in existence, both openly shared and restricted, is likely well over 400.

Even though many transit agencies created GTFS feeds with the primary purpose of benefiting from the free Google Transit trip planner, application developers, often not affiliated with the agency or Google, quickly realized that they could also create many new types of services based on the same GTFS transit data. As a result of third-party developer innovation, GTFS data is now being used by a variety of third-party software applications for many different purposes, including trip planning, ridesharing, timetable creation, mobile data, visualization, accessibility, analysis tools for planning, real-time information and interactive voice response (IVR) systems. In fact, in 2010, the GTFS format name was changed to the *General* Transit Feed Specification to accurately represent its use in many different applications outside of Google products.

The purpose of this paper is to provide a comprehensive overview of the opportunities to use GTFS for many different types of information services for the general public as well as internal agency operations. Many opportunities exist to create new services based on GTFS data — either to provide transit information through a greater range of delivery formats (e.g., new mobile transit applications), or to provide new ways of understanding and using transit information (e.g., for planning and analysis purposes).

For transit agencies who are not openly sharing their data, this paper will inform decisions on prioritizing and justifying investments in open data initiatives surrounding GTFS.

For transit agencies that already provide open access to their GTFS data, this paper will assist the agency in maximizing their investment in GTFS data by showcasing examples of many new types of applications that utilize the same GTFS data they are already producing.

For Departments of Transportation, Metropolitan Planning Organizations, and other intermodal agencies, this paper will assist them in understanding the current state-of-the-art in public transportation information and will help them integrate this data, and new types of services based on this data, into their existing intelligent transportation systems (ITS) to create true multimodal traveler information systems.

In the following sections, a brief summary of the GTFS format, methods to create GTFS datasets, and considerations for sharing GTFS data with the public are discussed. Then, an overview of the many different types of applications that are powered by GTFS data is presented.

CREATING AND DISSEMINATING GTFS DATASETS

Before a transit agency can benefit from Google Transit and many other transit applications, they must create and disseminate their data in the GTFS format.

Creating and disseminating a GTFS dataset involves the following general process:

1) The agency should understand the GTFS format, and determine how their data will fit into this format.
2) Determine if the agency is going to create and maintain the GTFS data in-house, or whether they will depend on external organizations for this service.
3) Select a process for GTFS creation and dissemination that matches with the agency's requirements
4) Determine if the agency is going to share their GTFS data publicly, or whether they will only share with select vendors (e.g., Google Maps).
5) Choose a dissemination method that maximizes the exposure of the agency's GTFS data for the chosen audience.
6) Share a list of third-party transit application using the transit agency's GTFS data with the general public

In the following sections, a more detailed discussion of the above steps is provided.

Overview of GTFS

GTFS represents fixed-route schedule, route, and bus stop data in a series of comma-delimited text files compressed into a ZIP file.

Figure 1 shows the contents of a GTFS ZIP file from Hillsborough Area Regional Transit (Tampa, FL) (HART) and the contents of the stops.txt file within it that contains information about the name, ID, and location of every HART bus stop.

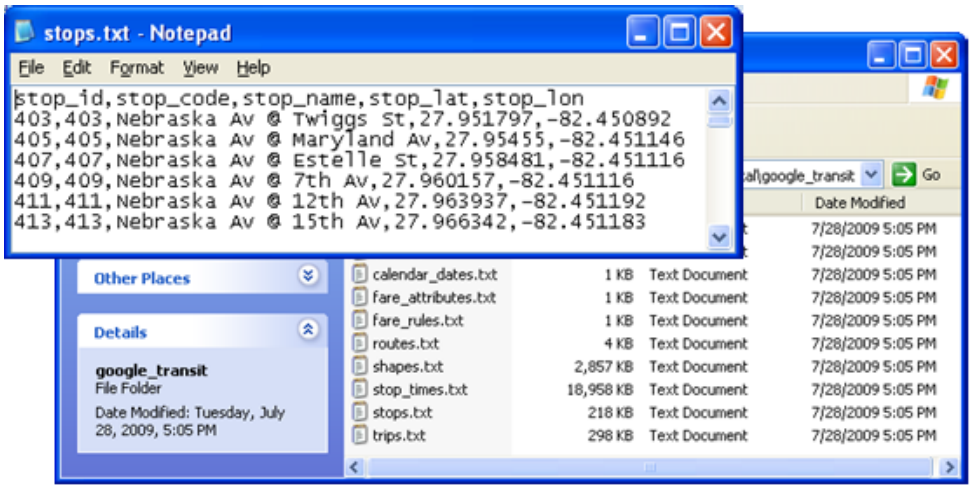

Figure 1 - A GTFS dataset from a transit agency consists of several text files within a ZIP file

The routes.txt file contains information about the routes of the transit agency, the calendar.txt and calendar_dates.txt files contain schedule information, and the trips.txt and stop_times.txt files contain information about the order of visitation of bus stops for a particular route according to a particular schedule. The shapes.txt file contains the spatial representation of a route alignment so it can be accurately drawn on a map.

A full explanation of all GTFS files and data fields is available on the GTFS reference website [2].

Creation and Maintenance of the GTFS dataset

Transit agencies must make the decision whether to format and maintain a GTFS dataset using their own personnel, or if they are going to outsource this task.

It is important to consider that a new GTFS dataset will need to be produced every time there is a change to the schedule to keep the transit services based on GTFS data up-to-date. Major schedule changes can occur 3-4 times a year for large agencies, although, depending on the impact on the transit rider, the agency may want to update their GTFS data more frequently to reflect smaller changes in service on a weekly or monthly basis. Therefore, when identifying a GTFS creation process, the maintenance and sustainability of the process must be considered.

In-house

If the agency has sufficient in-house technical expertise, they may wish to produce and maintain the GTFS feed themselves. Several of the industry-standard scheduling software packages from vendors such as Trapeze [5], HASTUS [6] , Connexionz [7], and Mentor Engineering [8] can often export agency data into the GTFS format, facilitating the GTFS creation & maintenance process. However, agencies should not necessarily assume that the output of these tools produces perfect GTFS data, as agencies have indicated that they often still need to perform manual data processing on the GTFS data exported from these tools before it will be acceptable for application use [9].

For agencies who do not have access to sophisticated scheduling software, there are free spreadsheet-based tools for creating and maintaining GTFS data such as and XLS Tools for Google Transit by Bob Heitzman [10], which were repackaged as "GTFS Builder" by the Rural Transit Assistance Program [11] . OpenPlans, a nonprofit 501(c)3 that produces open-source civic software, is working on an open-source web-based GTFS Editing Tool [12]. For agencies without high-quality bus stop inventories, the open-source GTFS-OpenStreetMap Synchronization tool (GO-Sync) can help leverage crowd-sourced improvements of their GTFS bus stop inventory [13]. There are also many educational resources available online from the transit developer community for agencies interested in creating a GTFS feed [14, 15].

Outsource

Vendors such as Trillium Solutions, Inc. [16], TransitEditor [17], and Next Insight Transportation Software [18] provide tools and services that can aid agencies in formatting and maintaining their data in GTFS format, ranging from online tools that are operated by the agency to a full service model where the vendor creates the GTFS data for the agency.

The cost for a transit agency to hire a vendor or consultant to create GTFS data is usually around $200-$500 per route, depending on the level of effort required [19]. Level of effort is determined by the number of stops, complexity and variation of the routes and schedules, and the availability and quality of existing stop location, schedule, and route alignment data.

GTFS Data Dissemination

Benefits for Public Dissemination of Data

Once an agency has determined a method for producing and maintaining GTFS datasets, they must consider who they will share the data with.

As mentioned earlier, some transit agencies choose to share their data only with select vendors (e.g., Google Transit). However, 49 of the top 50 largest transit agencies (by passenger miles) in the continental United States have openly shared their GTFS data [3]. Open data policies are not limited to only the largest agencies, though. According to Wong et al. [20], agencies of all sizes have opened their data. Among all agencies, in 2010 approximately 85 percent of transit miles traveled in the U.S. were on transit systems with open data [21]. The U.S. federal government has also prioritized an "open data initiative" to encourage government agencies to release their data to the public [22], and therefore open data has also been embraced on a federal level. Globally, there are estimated 261 agencies worldwide that have chosen to share their data publicly [3].

Wong et al. provide an extensive discussion of the industry status and benefits of open data, including significant cost savings to the agency, as of July 2012 [20].

Risks for Public Dissemination of Data

Transit agencies often cite concerns regarding perceived risks of releasing their data to the public, including:

1) Legal exposure due to the lack of accuracy of data

2) Loss of control of agency brand
3) Loss of advertising revenue on the agency homepage (if Internet traffic is directed to other sites, such as Google Transit, that provide transit services)
4) Loss of control of dissemination of transit service information

Wong et al. conclude that legal and brand usage concerns can be overcome, based on interviews and experience with five transit agencies [20]. Additionally, none of the agencies from this study reported any serious legal issues resulting from the release of GTFS data to the public [20]. TriMet also confirmed with the authors of this paper that they have not experienced any legal issues related to open data [23]. Readers interested in the legal aspects of open data may want to consult a presentation by the Open Knowledge Foundation on this topic [24].

The authors of this paper have discussed the issue of loss of web traffic and loss of control of dissemination of transit service information with TriMet in Portland, Oregon. TriMet stated that the number of visits to their website did not decline after sharing their GTFS data, and they feel that they have better control over transit information dissemination by openly sharing a GTFS dataset then they had previously without open data, due to a contractual relationship with users of their GTFS data [23].

Terms of Use for Public Data

As mentioned in the previous section, once an agency has decided it want to publicly share its data, it should examine possible guidelines for data users. Some providers of GTFS data provide a "Terms of Use" or a developer/license agreement that define guidelines for application developers using the agency's open GTFS data feed.

Many agencies that have a "Terms of Use" agreement that application developers must agree to when using the agency's data, including TriMet (Portland, OR) [25], BART (SF Bay Area) [26], Corona, CA [27], PSTA (Clearwater, FL) [28], HART (Tampa, FL) [29]. Other providers of GTFS data do not provide a license or terms.

The data described in GTFS is not sensitive or proprietary; rather it is information about services that is also published through printed timetables, maps, and fare schedules. If the agency does not deem it necessary to seek legal counsel, it may choose to release data without a license or with guidelines for use.

Based on existing examples in the industry as cited above, these agreements generally contain the following statements:

1. The agency reserves the rights to its logo and all trademarks. These marks are an indicator used for official information from the agency only.
2. The data is provided without warranties.
3. No availability guarantees are expressed or implied.
4. The agency retains full rights to the data.

Dissemination Methods for Public GTFS Datasets

After the transit agency has created the GTFS zip file and decided whether or not to include data use guidelines, it can be shared with application developers so that applications (e.g., Google Transit) can use the data. GTFS data is typically made publicly available by sharing the data at a

publicized URL. Developers and consuming applications can download GTFS data from the specified URL.

Two websites currently serve as the primary global directories of publicly accessible data:

- GTFS Data Exchange [30]
- Public Feeds wiki page on Google Transit Data Feed Google Code project [31]

Based on the previously cited references earlier in this paper, transit agencies with GTFS data should consider making this data public to best leverage their investment and maximize the availability of applications based on their GTFS data. The data can be made available on the websites listed above, as well as at the individual agency websites. Trinity Transit [32] is an example of a small agency that has chosen to make GTFS publicly available through its website, as has HART [33] and Pinellas Suncoast Transit Authority (PSTA) in the St. Petersburg/Clearwater area of Florida [34].

Another example of GTFS data publishing is a regional approach where all GTFS data feeds for a number of nearby agencies are listed on a single centralized site so they are easily discoverable by application developers. The following agencies publish a list of all the publicly available GTFS data for all agencies in the respective state:

- Oregon Department of Transportation Public Transit Division [35]
- New York State Department of Transportation [36]
- Massachusetts Department of Transportation [37]

Highlighting Transit Application Powered by GTFS Data

When applications are created by third-party developers using a transit agency's GTFS data, the agency may choose to make transit riders aware of these applications. One method of increasing awareness is to showcase certain applications on the agency's website.

The TriMet App Center [38] shows an example of a transit agency that publishes information about 3rd party applications. San Francisco Bay Area Rapid Transit (BART) provides another example [39]. Mendocino Transit Authority is an example of a small transit agency that provides an "App Center" [40]. City-Go-Round [3] is a global directory of third-party transit applications.

APPLICATIONS BASED ON GTFS

After an agency has created a GTFS feed and shared it with the public, it is able to access many different types of applications that are based on GTFS data.

An overview of these different types of applications is provided in the next several sections:

- Trip planning and maps– applications that assist a transit customer in planning a trip from one location to another using public transportation
- Ridesharing – applications that assist people in connecting with potential ridesharing matches
- Timetable creation – create a printed list of the agency's schedule in a timetable format
- Mobile applications –applications for mobile devices that provide transit information

- Data visualization – applications that provide graphic visualizations of transit routes, stops, and schedule data
- Accessibility – applications that assist transit riders with disabilities in using public transportation
- Planning analysis – applications that assist transit professionals in assessing the current or planned transit network
- Interactive Voice Response (IVR) – applications that provide transit information over the phone via an automated speech recognition system
- Real-time transit information – applications that use GTFS data along with a real-time information source to provide estimated arrival information to transit riders

It should be noted that only a subset of all applications that use GTFS data are presented in this paper. This paper discusses applications that provide services based on many transit agencies' GTFS data, and therefore are relevant on a country-wide scale beyond a specific city-sized geographic area. It is estimated that hundreds of GTFS-based applications exist around the world and provide information for only one or a handful of local agencies within a metro area. Interested readers are referred to other resources referenced in this report to discover these local GTFS-based applications.

Trip Planning and Maps

Several map and trip planner websites include transit information by using GTFS data. In order to make transit information broadly accessible, and reach as many customers as possible, it is recommended that transit information is made available on as many of these websites as possible.

Google Maps

The Google Maps transit trip planner is currently implemented for most transit agencies that publish GTFS, as Google was the first consumer of the GTFS format. Transit agencies participate through the Google Transit Partner Program [41], which is cost-free.

Google also provides a Hotel Finder site [42], which allows the user to easily find hotels within an estimated transit and walking distance of a chosen location on the map.

Beginning in June 2012, transit information was added to the Google Maps Application Programming Interface (API) [43]. This allows third-party applications to query Google's Directions API for transit directions and other information about transit services.

OpenTripPlanner

OpenTripPlanner (OTP) [44] is an open-source multimodal trip planner currently under-development and in a beta test phase for several regions in the United States and internationally. TriMet in Portland, OR has launched a production trip planner using OpenTripPlanner (Figure 2).

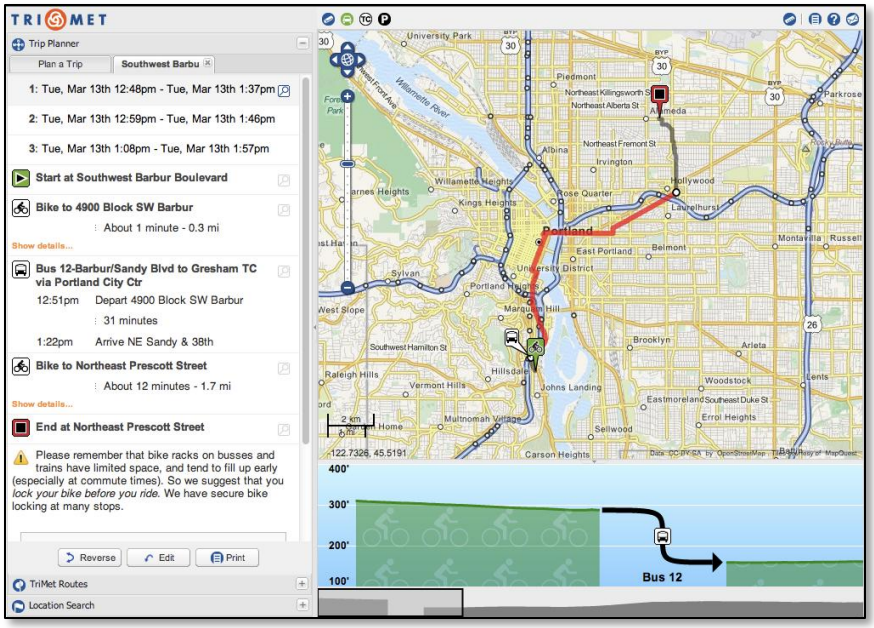

Figure 2 - Screenshot of public preview of OpenTripPlanner showing transit and bike trip in Portland, Oregon (rtp.trimet.org)

The multi-modal aspect of the trip planner means that it is possible to plan many types of trips using the trip planner, including transit-only (with walking), bike and transit, driving and transit (utilizing park and ride locations), bike-only, walking-only, or driving-only trips (Figure 3).

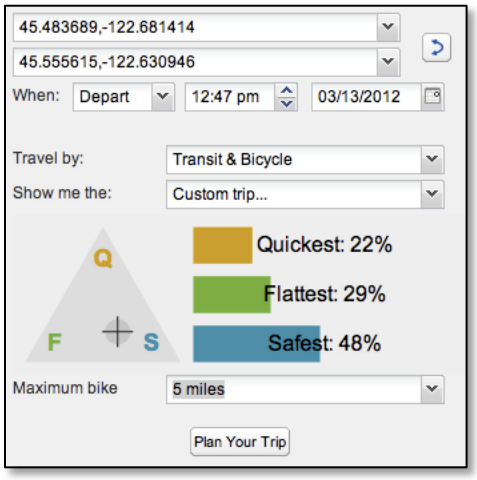

Figure 3 - Screenshot of OpenTripPlanner transit and bicycle trip preferences selector.

"Open-source" means that the source code of the application can be openly downloaded and examined. The software code of the software can be modified by a qualified software developer to customize and augment the software for particular local needs. Support can be provided by an in-house software developer or consulting software developer. This differs from "closed-source" application software which is typically purchased from a software vendor; subsequently the application code is only modified through updates issued by that software vendor. It is important to note that open-source software can be released under a variety of licenses, some of which

restrict the use of any derivative works of the source code. A detailed discussion of the advantages of open-source software is beyond the scope of this paper, so the interested reader is referred to additional resources [1, 45-48].

The non-profit organization OpenPlans provides a free "OTP Deployer" service [49] for agencies to preview OTP for their transit network. It is necessary to have GTFS data to upload to use this service. $5,000 is an estimated baseline cost for basic deployment and maintenance of OTP for one year. This estimate assumes 25 consulting developer hours at $100/hr, and a hosting cost of $2,500.

Bing Maps

Bing Maps [50], a service of Microsoft, began offering public transportation directions in 2010. Data for a handful of public transportation agencies is included in Bing Maps. Bing Maps ingests data in the General Transit Feed Specification (GTFS), as Google Maps does. Bing Maps publishes information about the Bing Maps Transit Partner Program [51], which offers transit agencies the opportunity to sign up for the Program and provide their data to Bing Maps. It is cost-free for transit agencies to participate. Bing Maps is integrating new agencies; however a timeline for adding new agencies is unclear.

Bing Maps offers roughly equivalent functionality as Google Maps with regard to transit directions. There is also a mobile app version of Bing Maps. Bing Maps also includes transit directions in their API, which allows 3rd party applications to query for transit directions and other information about transit services.

Hopstop

Hopstop [52], launched in 2005, was one of the original transit trip planning websites [53]. In 2011, Hopstop added functionality for planning trips for an additional 20 agencies, totaling coverage for 57 cities [54]. The Hopstop website asks transit agencies to email feedback@hopstop.com if they would like to be included in Hopstop directions [55]. In addition to directions, Hopstop provides transit maps and schedules for included agencies. It is cost-free for transit agencies to participate.

MapQuest

MapQuest [56] is a website for maps and directions, similar to Google Maps and Microsoft's Bing Maps. MapQuest incorporated public transportation directions in February 2011, and uses GTFS as the import format [57]. However, MapQuest has not announced a partner program or provided information about the process and terms for including public transportation data in the transit planning feature. At this time, it appears that all included agencies provide rail services. MapQuest offers participating agencies access to transit directions results through the MapQuest Directions API and MapQuest Open Directions API [57].

rome2rio

rome2rio [58] is an international travel search site (Figure 4). The site provides information about options for travel between any two given locations in the world by commercial air flights, rail, bus, driving, or a combination of modes. The website ingests data that is made publicly available at GTFS Data Exchange [30]. It is cost-free for transit agencies to participate.

If a transit agency is interested in having their data featured in rome2rio, it is recommended that transit agencies to make GTFS data available to rome2rio by directly contacting rome2rio.

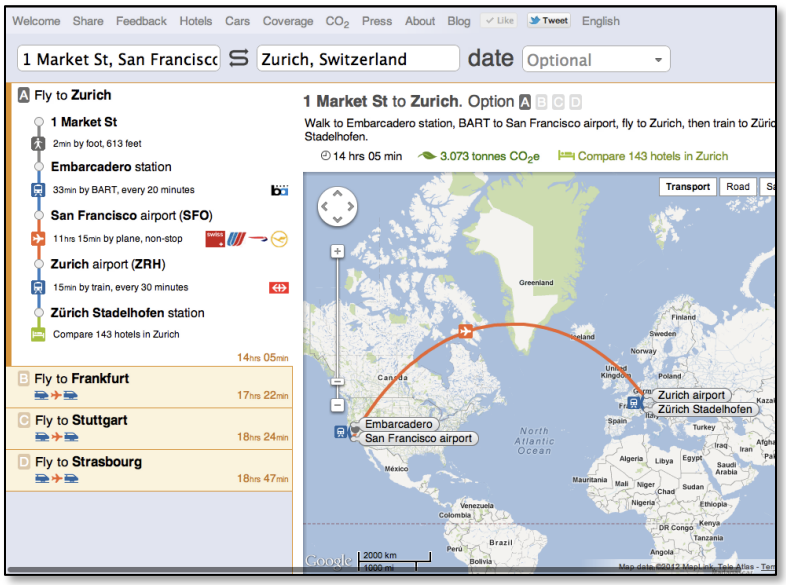

Figure 4 - rome2rio directions showing travel options from downtown San Francisco to Zurich. The directions include ground transit (BART in San Francisco, and local train in Zurich).

Ridesharing

Some transportation organizations are interested in helping people connect with ridesharing opportunities. Ridesharing, also commonly called "carpooling," is when two or more individuals share a private automobile to make the same or similar trip (to one or nearby destinations). Ridesharing can supplement public transportation services, and can reduce single-occupancy vehicle trips. There is emerging software that allows people to search for fixed-route transit services and rideshare opportunities through one interface.

Parkio

Parkio, Inc. is a Seattle-based company that provides a commute trip planner and parking services to private employers [59]. While the company has chosen to focus on serving private employers, its products demonstrate the possibility of providing an integrated map interface for discovering and reserving rideshare, fixed-route public transportation, private shuttle commute options as well as parking management. Parkio is available for a subscription fee.

Avego

Ireland-based Avego [60] offers services for "real-time ridesharing". Their service is largely mobile-based. The company also offers "Futurefleet", a suite of customer information, AVL, arrival estimate, and operations management systems for transit operators. Avego advertises that their services support intermodal connections [61], however, based on the product information pages at the Avego website, it is unclear how or if this integration is achieved through the software.

Timetable creation

TimeTable Publisher

TimeTable Publisher [62] is free, open source software that creates HTML (web-ready) and PDF (print-ready) timetables from information contained in a connected database or GTFS data file. TriMet [63] in Portland, Oregon uses TimeTable Publisher to create all its timetables, as does Hampton Roads Transit [64] in the south-eastern Virginia area. TimeTable Publisher includes a "compare differences" tool to find differences between schedule updates. The "compare differences" tool is only available when TimeTable Publisher is connected directly to a schedule database.

Mobile applications

The below software applications make transit information available to users of mobile phones through native mobile apps.

Google Maps

Google Maps [65] contains a transit trip planner, which is available for several devices including Android mobile phones, iPhones prior to iOS6, and Blackberries. Features vary by mobile platform. Currently, Google Maps for Mobile seems to be focus primarily on Android, although other platforms such as Windows Mobile and Java Micro Edition have been supported in the past. New iPhones with iOS6 will not have Google Maps or transit navigation features (see the "Transit App for iOS6 and Beyond" section below) [66]. Google Maps for mobile supports location-positioning on all devices that offer GPS features. Google Maps for Android devices offers the most complete feature-set, including a "Transit Navigation" feature that notifies transit passengers when they need to make transfers and alight from the vehicle for their destination.

Transit App for iOS 6 and Beyond

Beginning with Apple's iOS 6, transit routing directions will no longer be available within the default maps application on the iPhone, iPad, and iPod touch [66]. However, this default Maps application will link to 3rd party applications that provide transit routing information. To enable iOS device users to continue planning transit trips, the non-profit organization OpenPlans announced a project to create a universal transit planning app for all iOS devices. The mobile application will plan transit trips in any area where the transit agency has made GTFS data public. The effort to create the application is currently described on the crowd-sourced funding site Kickstarter [67].

Nokia Transport

Nokia Transport is a mobile application that became available in early 2012 [68]. The application is available on Nokia's Windows Mobile devices. The application provides transit directions for hundreds of transit agencies in North America by using publicly-available GTFS data.

RouteShout

RouteShout [69] is an application that allows users to receive scheduled and predicted arrival times via SMS or mobile application. Transit agencies that wish to be included in the application can request to be added; GTFS data is required to import service and schedule data. Real-time data can be incorporated if there is an installed AVL and arrival estimate system with the necessary interface. RouteShout also offers an API interface for accessing transit data [70].

Basic services are provided for free to participating transit agencies. SMS services are available at an extra subscription cost to agencies. A RouteShout administration interface (also available only with paid access) allows transit agencies to push alerts to customers that sign up to receive information pertaining to particular services.

Tiramisu

Tiramisu [71] is a mobile app created by Carnegie Mellon for Android and iPhone that crowd-sources real-time estimated arrival times, bus fullness, and rider experience based on users of the mobile application [72, 73]. As a result, the application is able to provide real-time transit information for portions of the transit systems where users have the application active on their phone without requiring an AVL solution on the bus. When crowd-sourced real-time information isn't available, Tiramisu shows the scheduled information from GTFS data or estimates based on historical arrival times or bus fullness. Tiramisu uses GTFS data as its data import format, but is currently available only in Pittsburg.

Data Visualization

Several apps that visualize a transit system by leveraging the GTFS data format are available.

Walk Score and Apartment Search feature

Walk Score [74] is a website created by the not-for-profit organization Front Seat (Figure 5). The purpose of the website is the help people quantify "walkability" through a numerical score. "Walk Scores" indicate the number of nearby amenities that are within walking distance. Walk Score's primary use has been for buyers of real estate who wish to convenience access to amenities. Walk Score is also used by people selecting an apartment or home to rent. In mid-2012, the travel booking site Hipmunk [75] added a "Walk Score" layer in its hotel mapping feature. This allows travelers to discover and select hotels that are located in convenient areas of a city.

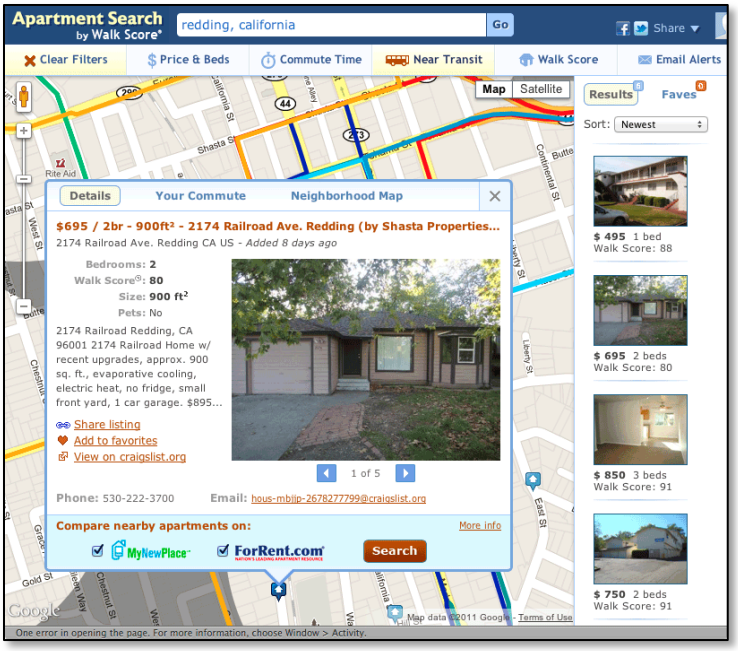

Figure 5 - Screenshot of Walk Score Apartment Search feature.

In August 2010, Walk Score incorporated Transit Score and commute reports [76]. According to the Front Seat press release, "Transit Score provides a 0-100 rating indicating how well an address is served by public transportation. Ratings range from 'Rider's Paradises' where multiple transit options are available within a quarter of a mile to areas with limited or no nearby public transportation."

Walk Score uses public GTFS from GTFS Data Exchange [30]. It is cost-free for transit agencies to participate.

Mapnificent

Mapnificent [77] shows how far it is possible to travel on public transportation from a given location for over 50 cities throughout the world. The application interface provides a slider control to adjust maximum travel time. As the slider is adjusted, the highlighted area on the map showing travel range expands and contracts. Mapnificent also includes a JavaScript API that lets developers integrate a Mapnificent overlay into applications that use the Google Maps API. Mapnificent uses public GTFS from GTFS Data Exchange [30]. Not every agency with a public feed is included, but the developer, Stefan Wehrmeyer, will often add agencies if requested. It is cost-free for transit agencies to participate.

Accessibility

Several applications have been developed with the purpose of assisting transit riders with disabilities. These applications also import GTFS data to obtain knowledge of the transit system.

Sendero Group BrailleNote GPS

The Sendero Group makes a line of BrailleNote devices and mobile applications. The BrailleNote devices are portable computers with refreshable braille displays for people who are blind or seeing-impaired. The BrailleNote GPS devices and LookAround mobile applications

allow users to find transit stops from many major U.S. transit agencies. The company will incorporate transit stops into their database from public GTFS data for any agency based on user request [78].

Travel Assistant Device (TAD)

The Travel Assistant Device (TAD) mobile application grew out of a research project conducted at the University of South Florida's National Center for Transit Research [79, 80]. The travel assistance system for sight-impaired or intellectually-disabled passengers allows them to plan a transit trip and download information to a GPS-enabled mobile phone with the TAD mobile app installed. Phones with the application installed give audio and vibrating alerts when it is time for the passenger to pull the stop cord and alight from the bus.

The TAD system uses GTFS data to import up-to-date schedule and stop. The product is being commercialized by DAJUTA [81], a Florida-based company. Updates on the TAD project can be found at the USF TAD website [82].

Planning & Analysis Tools

GTFS data can also be leveraged to aid transportation planners, including transit staff, when planning changes to the transportation or transit network.

OpenTripPlanner: Analyst Extension

In addition to features for trip planning, OpenTripPlanner (OTP) includes analysis tools within the core software package. For example, OTP servers can produce travel time graphic representations (i.e., isochrone) map tiles. OTP developers are now building out this framework to support off-line batch computations using large sets of origins and destinations, whose locations and attributes can be loaded from CSV, Shapefile, or raster file formats. Functions applied over the set of origins and destinations can produce cumulative opportunities accessibility measures, which are conceptually similar to an advanced version of Walk Score or Transit Score feature [83]. Therefore, OTP is also usable as a visualization application.

The above-described capabilities are being developed as part of the "Analyst Extension" for OTP. More information on OTP Analyst Extension is available in the OTP Analyst portions of the OpenPlans [84] and OpenTripPlanner [85] websites.

Graphserver

Now largely considered a predecessor to OpenTripPlanner, Graphserver [86] is perhaps the original open-source multimodal trip planning software. However, Graphserver, written in C and Python, is intended for software developers who are interested in algorithms research and transit analysis, not as a customer-facing multimodal trip planning or analysis solution. Graphserver core software development seems to have been inactive over the last year, although there is still activity on the Graphserver developers group. Transit agency staff interested in multimodal trip analysis who do not have a background in software development are directed to the OpenTripPlanner Analyst Extension.

ODOT-sponsored proof of concept: "GTFS Data as a Basis for Optimization of Large Scale Transit Networks"

The Oregon Department of Transportation (ODOT) is beginning a research project to use GTFS data to analyze the transit network in the state. This research project will result in an instance of a prototype tool or tools to report on and analyze the Oregon transit network. This tool is anticipated to be open source, so it can be implemented by other agencies. More information is available in the FY 2013 Research Problem Statement [87].

Regional Public Transportation GIS Architecture and Data Model

Many transportation planning organizations seek to better utilize public transportation data within a holistic planning process that involves other modes of transportation. However, achieving this goal is difficult if obtaining current public transportation network data and integrating this information into an enterprise GIS database is very effort-intensive.

The Florida Department of Transportation (FDOT) District 7 identified the need to obtain and view spatial data from many public transportation agencies within the district and region to aid in their multimodal planning efforts. A research team at the University of South Florida's National Center for Transit Research completed a prototype Regional Public Transportation GIS Architecture and Data Model in May 2012 [88]. The research project has produced tools that automatically download new GTFS datasets from the regional transit agencies and store them in the FDOT D7 enterprise geodatabase. Additionally, a web-application has been developed to visualize and query transit data alongside other data, such as proposed, planned, and in-progress road construction projects. The open-source software is available under the Apache 2.0 license on Github [88].

Transit Boardings Estimation and Simulation Tool (TBEST)

TBEST Transit Modeling and Analysis software, funded by the Florida Department of Transportation, is used for short-term transit ridership forecasting, market analysis, and network accessibility analysis. TBEST is designed to support transit agency strategic and service planning initiatives including the development of ridership forecasts within 10-year Transit Development Plans [89]. TBEST can import GTFS data. The TBEST GTFS import tool has been implemented for service and strategic planning at LYNX in Orlando, Florida and is used to update new service bids [90].

To use the TBEST GTFS Import Tool, the following software and data are required:

- ESRI ArcGIS (ArcView license) installed locally on the machine. No extensions are required.
- Census data compatible with TBEST data input requirements
- Address-based (point) or zonal (polygon) employment data
- Optional: parcel centroids containing land use data [91]

Pre-formatted Census, employment and parcel data are available for download for Florida TBEST users.

TransCAD 6.0

TransCad is a commercial travel demand forecasting software product sold by Caliper Corporation. Starting with TransCAD 6.0, GTFS file format input and GTFS-based best route solutions are supported [92].

GTFS-based Planning and Research

While some activities have not produced tools or applications that are publicly available, several studies are mentioned in this section to illustrate existing examples of agencies leveraging GTFS data as part of their own research or planning studies. The Delaware Valley Regional Planning Commission has used GTFS data as the main source of data when developing its regional forecasting model [93]. The Brookings Study of Transit and Jobs in America [94] used GTFS data to determine how well transit connects people with their jobs. A research project by the National Center for Transit Research identified opportunities to use GTFS data to support service planning and operational activity and developed a prototype application that integrated GTFS data with an automatic passenger counter (APC) for analysis and visualization [95].

Interactive Voice Response (IVR)

Interactive Voice Response (IVR) telephone systems can provide travel directions by phone. At least two vendors offer phone-base trip planning using voice recognition. Pricing for these products depends on features selected, agency and region size, and call volume. Ontira Communcations, Inc. offers BusLine. LogicTree offers TransitSpeak and TravelSpeak. The systems with voice recognition can be very expensive, and have been noted to provide a frustrating user experience [96].

Real-time Transit Information

The basic GTFS format contains only static (i.e., infrequently changing) transit information such as schedules, routes, and bus stops. Therefore, a GTFS dataset alone will not enable real-time transit information services for a transit agency. However, for many real-time applications GTFS data is also required to describe basic information about the transit system. GTFS-realtime [97] and SIRI [98] are emerging formats implemented by a number of agencies for real-time transit data such as estimated arrival times based on real-time vehicle positions. Although real-time transit data formats are outside the scope of this paper, several applications are presented below for real-time transit information that require the basic GTFS dataset in addition to another real-time information source. These applications aren't usable without the basic GTFS dataset, so GTFS plays an important role in these applications.

OneBusAway

OneBusAway [99] is an open-source software system for real-time transit information that grew out of research at the University of Washington. The initial OneBusAway deployment was in the Puget Sound area in Washington, although OneBusAway is in the process of being deployed in several other locations in both production and development deployments [100]. MTA in New York is using OneBusAway software as the foundation of their Bus Time system [101]. OneBusAway uses GTFS data for the basic description of the transit system. Real-time information can be injected into the OneBusAway system using a variety of formats [102], including GTFS-realtime, SIRI, and ACS Orbital Orbcad.

NextBus

NextBus [103] is a vendor that provides real-time information service for many transit agencies in the United States. While another data source such as an AVL system must provide real-time data information, NextBus uses GTFS data to import basic information about the transit agency's routes, stops, and schedules.

TransLōc

TransLōc [104] is a vendor that provides real-time information and visualization for transit and shuttle systems. TransLōc reports that their software imports GTFS as the basis of their transit network and schedule data.

CONCLUSIONS

GTFS has become a de facto standard for representing scheduled transit data and is being used by many different types of applications. Transit agencies now have the opportunity to publicly share transit data in GTFS format and leverage a wealth of new services based on this information, typically at little to no cost to the agency. Any Department of Transportation, Metropolitan Planning Organization, or other intermodal agency can also leverage this information to help create true multimodal traveler information systems.

While an overview of many informational resources are presented in this paper, the pace of development around GTFS and information technology for public transportation can be very rapid. As a result, many new opportunities to leverage GTFS data are expected to emerge over the next several years. For the most recent information in this area, the interested reader is referred to the following resources:

- City-Go-Round [3]
- Transit Developers Group [105]
- The Transit Wire [106]
- Trillium Solutions, Inc. blog [16]

ACKNOWLEDGMENTS

The authors wish to thank San Benito County Local Transportation Authority in Hollister, California, Eastern Sierra Transit Authority, in Bishop, California, as well as the Florida Department of Transportation, for funding in part the collection and organization of this information. It should be noted that this paper is intended as an informational resource – mention of an application or vendor service does not imply endorsement of that application or vendor.

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