Redesign of Curricula in Transit Systems Planning to Meet Data-Driven Challenges

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Abstract
As our society and technology change the way we use and perceive public transit systems, contemporary professionals need to be equipped with the skills to manage transportation systems to keep up with modern demands and challenges. Information Communication Technologies and data ubiquity represent great potential advances in transport systems; however, the challenge of transferring the knowledge from research and academia remains a significant barrier. This paper contributes to the literature in two ways: it serves as a benchmark of the challenges in transit systems planning education today, and it is a reference guide for future educators to find resources to create and refine effective educational programs in this area. A case study of a sample teaching module for transit systems planning in the Greater Toronto Area is presented with guidelines to teach 1) models of data-driven flexible transit services; 2) technologies to integrate and visualize user and systems data; and 3) methodologies to evaluate demand for such services at a societal level.

Keywords: public transport, mass transit, travel demand, systems planning, Big Data
1. Introduction

The skills needed to manage, plan, operate, and design an urban public transit system are rapidly changing due to the rapid pace of data-driven technologies and, subsequently, the proliferation of new mass transportation business models. The prevailing role of information and communication technologies (ICT) and the emergence of “Big Data” analytics (LaValle, 2011) has made data more available than ever before, for both users and transit operators, about demand as well as the transit systems. The dominance of ICT in transit management technologies is readily evident from a view of the most recent Intelligent Transportation Systems (ITS) Architecture 7.0, which features such examples as in-vehicle information systems, ride-sharing, dynamic routing demand management, and in-vehicle surveillance (RITA, 2009). User-based ICT for transit trip planning and advanced smartcards make it easier than ever to travel by multimodal transportation. Many start-ups in the private sector are finding opportunities to leverage the new technologies to provide competitive, flexible multimodal transport services including vehicle/bike sharing (Zipcar, BIXI), ride sharing (Zimride), taxi management (Uber), parking management (SF Park), and transit trip planning (Flybits). Figure 1 illustrates the trail of concepts derived from the availability of data where the technology of each level is reliant on the level above.

![Figure 1](image-url)

**Fig. 1. Knowledge transfer challenges in transit derived from modern innovations in ICT.**

Is it possible to incorporate these new technologies and business models to solve existing problems at a societal level? How do we forecast the public’s use of these new alternatives and plan accordingly? It is clear that the knowledge needed by a professional is quite different from 20 or even 10 years ago, as there is a much greater emphasis on data-driven methods. In 2003, Google did not even exist as a publicly traded corporation, whereas today professionals can access real time traffic data and updated transit schedule information directly from the technology giant. The knowledge transfer problem is further exacerbated by the simultaneously growing urgency for better transit systems to stave off environmental decline and accommodate global urbanization.

Unfortunately, this challenge towards educators has largely been unanswered. A number of recent studies already agree that there are insufficient training mechanisms to meet these new
challenges (SR 275, 2003; Bart and Reep, 2013). In contemporary graduate programs, even among the top transportation research programs, advanced data-driven transit modeling is not very evident.

Many ICT associated topics and others are not covered at all, or in limited form. Popular textbooks and course notes (e.g. Vuchic, 2005; Ceder, 2007; Daganzo, 2010) cover these topics peripherally and acknowledge them as ongoing issues that need further understanding. For example, flexible transit systems are covered primarily from a systems side without a deep consideration of user demand for such services (a new edition of Ceder’s book in 2014 is expected to overcome some of these concerns on user demand and behaviour). The result is that private startups can be built, but public agencies have no tools available to them to evaluate these alternatives at a societal level. On the demand side, educators teach basic network assignment concepts and mode choice models for fixed route, fixed schedule services. Most transit network assignment methods are extended from road traffic methods, which do not emphasize the scheduling aspects explored recently (Tong and Wong, 1999; Nuzzolo et al., 2001). This means students cannot capture the effects of alternatives that modify schedule-based spatial-temporal constraints of travellers, of which flexible transit is comprised. Mode choice focuses on trip-end level mode choices without the spatial-temporal constraints present in flexible services with abundant information. Part of the issue is clearly research-related (Chow et al., 2013), as it pertains to the splintering of the transportation field as a multidisciplinary science. But assuming we can address the research aspects, what are the knowledge transfer challenges that lay before us?

The contributions of this study are twofold. First, we highlight these challenges for a modern educational program in advanced transit systems planning, one that is driven by ubiquitous data. Research and technology advances are reviewed from the perspective of new skill sets and knowledge required from professionals. Second, we present a case study of a set of modules and tutorials that target key components of updating a transit systems planning curriculum to meet those challenges. This case study includes a set of concepts and methods that should be covered, those that cannot be covered due to lack of methods, and guidelines on using existing tools currently available to educators to proceed toward that future.

2. The gap between research and knowledge transfer

This section summarizes research developments in contemporary transit systems planning and connects them to knowledge transfer needs for students and professionals. The topics of transit researchers are in many cases specific and advanced, but the trends in research represent a shift in the way public transportation options are perceived, planned, and used. This section lays out a cross-section of graduate level transit courses, the trends in research in this area, and finally discusses the growing disconnect between the two.

2.1 Survey of programs

A survey of educational programs offered by some of the top universities in transportation education was conducted. This is not meant to be a comprehensive survey; it is merely a sample to capture the extent of transit systems planning education around the world. Table 1 outlines the subjects covered by transit-related courses at schools reputed for their transportation engineering programs based on publications and research. An initial list was obtained based on top schools in transportation research by h-index (Chow, 2013).
TABLE 1  Subjects covered by graduate level transit courses at a sample of transportation programs with keywords from course descriptions

<table>
<thead>
<tr>
<th>School</th>
<th>Course Name</th>
<th>Transit Topics Covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delft University of Technology</td>
<td>Railway Traffic Management</td>
<td>Modeling, analysis, simulation, scheduling (for railways only)</td>
</tr>
<tr>
<td></td>
<td>Urban Planning and Transport Networks</td>
<td>Demand, mode choice, multi-modal systems, network design</td>
</tr>
<tr>
<td>Georgia Institute of Technology</td>
<td>Transit Systems Planning and Design</td>
<td>System design, planning, operations, intermodal terminals</td>
</tr>
<tr>
<td></td>
<td>Urban Transport Planning</td>
<td>Policy, modeling, environmental effects</td>
</tr>
<tr>
<td>Hong Kong University of Science and Technology</td>
<td>Transportation System Operations</td>
<td>Urban transit operations and management</td>
</tr>
<tr>
<td>Imperial College London</td>
<td>Transport Engineering and Operations</td>
<td>Introduction to ITS, principles of public passenger transport operation</td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td>Public Transportation Systems</td>
<td>Data analysis, performance analysis, route and network design, fare structure</td>
</tr>
<tr>
<td></td>
<td>An Introduction to Intelligent Transportation Systems</td>
<td>ITS technology, system architecture, transportation strategies</td>
</tr>
<tr>
<td>National University of Singapore</td>
<td>Transportation Management and Policy</td>
<td>Demand management, policy, operations, ITS</td>
</tr>
<tr>
<td>New Jersey Institute of Technology</td>
<td>Public Transportation Operations and Technology</td>
<td>Technology, operations, system analysis, advances systems</td>
</tr>
<tr>
<td>Ohio State University</td>
<td>Urban Public Transportation</td>
<td>Service planning, route design, operations, modeling</td>
</tr>
<tr>
<td>Pontificia Universidad Católica de Chile</td>
<td>Transporte Público (Public Transport)</td>
<td>Planning, operation and management, technology, social aspects, multi-modal systems, scheduling, fare structure</td>
</tr>
<tr>
<td>Texas A&amp;M University</td>
<td>Advanced Surface Transportation Systems</td>
<td>Operations, traveller information systems</td>
</tr>
<tr>
<td></td>
<td>Urban Public Transportation Planning</td>
<td>Planning, operations, legal aspects, urban and rural modes</td>
</tr>
<tr>
<td>University of California - Berkeley</td>
<td>Public Transport Systems</td>
<td>Operation and management, vehicle technology, policy</td>
</tr>
<tr>
<td>University of California – Irvine</td>
<td>Transit Systems +Planning</td>
<td>Vehicle technology, short-range planning, data collection/analysis, mode choice</td>
</tr>
<tr>
<td></td>
<td>Transportation Data Analysis I &amp; II</td>
<td>Data sources, sampling techniques, causal modeling, discrete choice</td>
</tr>
<tr>
<td>University of Hong Kong</td>
<td>Engineering for Transport Systems</td>
<td>Choice of system, fixed-track systems, policy, planning, operation</td>
</tr>
<tr>
<td>University of Minnesota</td>
<td>Transit Planning and Management</td>
<td>Demand management, system performance, transit-oriented development, alternative transit modes</td>
</tr>
<tr>
<td>University of Texas - Austin</td>
<td>Public Transportation Engineering</td>
<td>Demand forecasting, operations, scheduling</td>
</tr>
<tr>
<td></td>
<td>Metropolitan Transportation Studies: Applications With TransCAD GIS</td>
<td>GIS fundamentals, spatial analysis, four-step demand forecasting and modeling</td>
</tr>
<tr>
<td></td>
<td>Operation of Transportation Facilities</td>
<td>Fleet management, flow control</td>
</tr>
<tr>
<td></td>
<td>Logistics</td>
<td>Vehicle routing, public transportation system design</td>
</tr>
<tr>
<td>University of Toronto</td>
<td>Public Transit Operations and Planning</td>
<td>Operations, planning, line and network design, transit economics</td>
</tr>
<tr>
<td></td>
<td>Public Transport</td>
<td>Analysis, optimization, data collection, scheduling, ITS, ridership forecasting</td>
</tr>
</tbody>
</table>
A deficiency which can be gleaned from Table 1 is the lack of technology and data for transit. This includes ICT and ITS technologies as well as GIS and in-vehicle technologies such as Automatic Vehicle Location (AVL) and Computer-Aided Dispatch (CAD). Additionally, there is a gap in instruction in transit demand forecasting, one that is integrated with systems design and development. Not all courses listed are dedicated solely to transit; there are ‘urban transport systems’ and simply ‘transportation systems’ courses which cover transit peripherally. Of course, this survey is only an overview based on course descriptions, but the conclusions reinforce the literature (SR 275, 2003; Bart and Reep, 2013).

2.2 Research trends

Table 2 illustrates a selection of current research (not meant to be comprehensive) that can be categorized by these areas that connect with technological trends observed in society. However, there remains a large gap between research and practice. This gap is evident by the absence or limited applications of these methods.

<table>
<thead>
<tr>
<th>Research Area</th>
<th>Authors</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Transit Solutions: Flexible Transit</td>
<td>Cortés &amp; Jayakrishnan</td>
<td>2002</td>
</tr>
<tr>
<td></td>
<td>Dessouky &amp; Zhao</td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td>Quadrifoglio &amp; Li</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>Nourbakhsh &amp; Ouyang</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>Alshalalfah &amp; Shalaby</td>
<td>2012</td>
</tr>
<tr>
<td></td>
<td>Bartholdi &amp; Eisenstein</td>
<td>2012</td>
</tr>
<tr>
<td></td>
<td>Chow &amp; Sayarshad</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>Nair, Miller-Hooks, Hampshire, &amp; Bušić</td>
<td>2013</td>
</tr>
<tr>
<td>AVL/CAD</td>
<td>Lu, Liu, &amp; Calami</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Hickman</td>
<td>2004</td>
</tr>
<tr>
<td></td>
<td>Jung, Jayakrishnan, &amp; Park</td>
<td>2013</td>
</tr>
<tr>
<td>User Data</td>
<td>Lau, Tham, &amp; Luo</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>Chow</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>Tirachini</td>
<td>2013</td>
</tr>
<tr>
<td>Integrated Systems Planning</td>
<td>Guihaire &amp; Hao</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td>Chen, Tan, Claramunt, &amp; Ray</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>Wahba &amp; Shalaby</td>
<td>2011</td>
</tr>
<tr>
<td>Systems Representation</td>
<td>Derrible &amp; Kennedy</td>
<td>2009</td>
</tr>
<tr>
<td></td>
<td>Hadas &amp; Ranjitkar</td>
<td>2012</td>
</tr>
</tbody>
</table>

The consensus captured by the comparison of curriculum offerings (Table 1) and emerging developments in research and practice of public transport systems (Table 2) result in a list of key educational areas which need improvement. Some of the key developments and how they translate to educational needs are discussed in the subsequent sections.
2.2.1 System representation: geographic information systems
With such a large quantity and variety of transportation-related data available, spatial data management has become a cornerstone skill required of professionals. Geographic Information Systems (GIS) are an important part of transportation planning at a system level. Papacostas and Prevedouros (2000) express that the question is no longer of whether to use GIS but of which one to select. GIS packages for transportation, or GIS-T, are excellent tools for transportation system analysis. TransCAD, whose specific capabilities will be presented in greater detail in the sample module presented later in this paper, is one such example.

While professionals are generally equipped with this skill, recent developments in ICT and social media have resulted in an evolution of GIS applications to mobile platforms and real time management. In addition, professionals need to be able to manipulate “systems of systems” to handle the interactions between data sets on multiple scales and layers.

2.2.2 System data: general transit feed specification
There are many sources of transit systems data, depending on which agency or operator is being considered. In the United States, the National Transit Database provides an example of valuable systems information including operating costs and vehicle inventories (NTD, 2013). For those seeking readily available public data, one source is Google.

Google Transit is a popular medium for the public to access transit data in a way that makes it easy for transit riders (and potential transit riders) to plan their trips using a visual interface as opposed to reading through schedules. Derby (2012) points out the significance of Google Transit and it being “a welcome and helpful tool for public transit users”. The format used is called General Transit Feed Specification (GTFS) which is a series of text files that contain route and stop, schedule, and other data (Google, 2012). Anyone who subscribes to the feed – researchers, public or other agencies, or third-party transit app developers can access and use this data. An important part of GTFS, and another appealing factor, lies in the ‘F’ – ‘Feed’; the constant availability of updates. Updated files are made available and the old ones are archived externally. Recently introduced to various cities around the world (including York Region in the GTA) is a real-time version of GTFS which utilizes Automatic Vehicle Location (AVL) to provide transit riders with the actual arrival times of vehicles instead of the scheduled times (Derby, 2012).

GTFS has become a de facto industry standard for storing and distributing transit data in part because of the convenience of its application to a platform popular with transit users. Despite no direct cost being associated with GTFS, Dion et al. (2011) note the cost of staff to prepare and maintain GTFS data, particularly in small agencies and when staff has no prior experience. Furthermore, GTFS is not limited to the Google platform, but also on various GIS. Agencies in American cities which opted to use third-party trip planners spent significantly more (US$ 80 000-250 000 versus US$ 950-9 500) than those using Google Transit, depending on the complexity of the system.

2.2.3 Integrated systems planning: automatic vehicle location and computer aided dispatch
Models exist for the operation of flexible transit services (Dessouky and Zhao, 2007; Nourbakhsh and Ouyang, 2011; Alshalalfah and Shalaby, 2012), as well as for determining optimal densities for their implementation (Quadrifoglio and Li, 2009). Some agencies do operate flexible, demand-responsive routes—Winnipeg Transit and the Los Angeles County Metropolitan Transit Authority are examples—but the technology for their efficient operation
has, for the most part, not yet made it into practice. For the systems mentioned, customers call in stop requests and their acceptance or rejection is made at the discretion of the bus operator. Automatic Vehicle Location (AVL) and Computer-Aided Dispatch (CAD) are an integral part of managing a fleet of vehicles whose routes are dynamic (Cortés and Jayakrishnan, 2002; Jung et al., 2013). AVL/CAD also allows for innovations in optimizing scheduling and operations (Lu et al., 2003).

2.2.4 Integrated systems planning: new public transportation solutions

While fixed-route transit is more cost-effective than flexible service, fixed-route does not provide adequate service to less densely populated areas (Dessouky and Zhao, 2007). Different options exist when considering DRT as an alternative. There is a fully flexible (i.e. flex-route and flex-schedule) alternative, where the route served is an area, as opposed to the traditional linear route (Nourbakhsh and Ouyang, 2011), or what is known as Mobility Allowance Shuttle Transit or MAST. MAST service follows a fixed route but may deviate from it within a ‘band’ to make demand-responsive pick-ups or drop-offs, usually following a no-backtracking policy (Dessouky and Zhao, 2007). These services have great potential in suburban areas or in connection with fixed-route services like park-and-ride facilities. This opportunity is evident in the Greater Toronto Area on the GO Train system and in the San Francisco Bay Area on the BART system, where flexible transit or shuttle service has been studied (Ceder, 2007; Alshalalfah and Shalaby, 2012). With these new ways of approaching suburban and rural transit, good quality transit service no longer has to cater only to high population densities (Mees, 2010).

Complete multi-modal systems are a method of providing the best service to transit riders. Along with DRT and shuttle services, vehicle or ride sharing programs can be effective alternative transport solutions. Bicycle sharing, for example, can help solve the ‘last mile’ problem for travelers; providing transport between transit stations and travelers’ final destinations (DeMaio, 2009). Bicycle and other vehicle sharing programs are methods to diversify transportation options and reduce congestion in cities (Nair et al., 2013; Chow and Sayarshad, 2014).

2.3 Summary of gap between education and the future of transit practice

We have shown the abundance in opportunities and issues today’s transit planning, and how practitioners are generally lacking in skills to address the issues or benefit from those opportunities. The challenges in closing the gap require multidisciplinary skills that include social sciences and technological understanding (Schlossberg and Larco, 2013) present in innovative transit solutions from academia and bringing such ideas into practice through the education of those opting to be practitioners rather than continuing in academia. This issue is not one faced by transit professionals alone; for example, the railway industry also suffers from a long disconnect between education and research (Lautula, 2013). Lautula (2013) shows the perceived benefits of partnerships between universities and railroad agencies in both the European Union and the United States.

In revising our curricula to address these issues and opportunities, we need to consider how to more directly integrate practical technical skills in higher learning for transit systems planning, particularly in graduate level engineering programs. Modules need to be built from a set of ‘new fundamentals’ which provide students with a better foundation for the future of public transport. As we examine ways to create a more data-driven transit systems planning
curriculum, these research trends suggest one that should be more conducive to the following three key concepts:

1) models of data-driven flexible transit services;
2) technologies to integrate and visualize user and systems data; and
3) methodologies to evaluate demand for such services at a societal level.

3. Curriculum challenges and recommendation

3.1 Recommended changes

To be more specific, changes to educational modules are suggested. Three examples are presented of how a curriculum can be modified, drawing from the knowledge areas set out in Table 2 along the dimensions specified at the end of Section 2. The following suggestions include a broad range of potential improvements which represent contemporary research, implementation feasibility, and practical benefits.

3.1.1 Transit assignment (traditional and flexible)
Like traffic planning (which is often presented in much more detail than transit planning), transit planning should be examined with a systems approach. Fixed-route urban transit is the appropriate choice in most situations and is almost exclusively used in practice. As such, traditional assignment methods should be covered. Both frequency-based methods (Spiess and Florian, 1989) and schedule-based methods (Tong and Wong, 1999; Nuzzolo et al., 2001) should be covered.

For certain demand densities, however, flexible transit offers riders a better level of service than a fixed-route vehicle (Quadrifoglio and Li, 2009). Ceder (2007) briefly describes a simulation-based approach for a feeder shuttle using a shortest-path algorithm. There are other methods such as the MAST model (Dessouky and Zhao, 2007) and more flexible feeder systems as in (Cortés and Jayakrishnan, 2002; Jung and Jayakrishnan, 2011; Alshalalfah and Shalaby, 2012). While tools may not be available to teach these methods in an experimental setting, students should be made aware of their existence and the benefits in planning and operations. Demand for different design configurations of these services also needs to be addressed. If we change the transit service from a fixed-route service to a flexible service, how would demand for the service change, both spatially and temporally? Concepts related to schedules, such as activities and logistics (Chow and Recker, 2012), should accompany this material.

3.1.2 GIS visualization of transit systems

Today’s multimodal urban strategies require the analytical capabilities of GIS-T to consider the different modes (Chen et al., 2011). Students need to be comfortable importing systems and user data onto a GIS platform, and manipulating it into various scenarios to visualize and evaluate. With increasing AVL and GPS applications in transit (e.g. Bertini and Tantiyanugulcha, 2004), simple experimental exercises based on creating one’s own GPS trajectory with a mobile device (e.g. smart phone or tablet) and importing it onto a GIS platform for visualization would also be useful. A “system of systems” perspective can be covered by teaching students to consider dependency of one GIS layer to another data source so that interconnected systems can be visualized.

The sample module provided in Section 4 includes the process of creating a visual mode which should be included in a transportation demand modeling course: researching and accessing
various data sources and modern data formats, manipulation and analysis of transport system models using GIS-T, and considering multimodal systems.

3.1.3 Applications of transportation user data
Intelligent Transportation Systems applications based on ICT are very popular with transit users and indeed are an important part of today’s transport systems. This data can be used to create systems from cyber-physical environments (Lau et al., 2011) or innovative fare collection techniques like smart cards or fare coupons (Chow, 2014). Econometric models are often taught to evaluate costs or demand as a function of sociodemographic factors. However, as more transit systems adopt these advanced fare collection systems and users are able to plan ahead of their transit trips (de Borger and Fosgerau, 2012) with advances in ICT, there should be more opportunities to teach students machine learning concepts and advanced artificial intelligence for statistical inference. One useful exercise may be for a student to design an automated data collection process related to a mobile device, and execute (or simulate, if setting up such a collection process is not feasible at the time) the data collection while streaming it onto a GIS platform. As the data is received, the student can test a handful of forecast or learning models to learn the challenges of managing data to inform systems designs.

3.2 Feasibility of including various topics into the curriculum
These suggested modules can be feasibly incorporated into a curriculum by adding new transit courses and/or altering existing ones. To address the multidisciplinary nature of modern transport planning, programs could make use of courses from other faculties for the instruction of topics outside of the specific domain of ‘transportation’ (e.g. urban planning, data management). Furthermore, to address the issues of new, specific technologies, it may be most effective to teach the basic skills and framework for such technologies. Dietz (1995), speaking generally of training engineers in this digital age, believes that teaching the basics, or fundamentals, along with the skills to learn can be an effective way of preparing engineers for the modern industry. This is similar to the model suggested by Bart and Reep (2013), who also advocate teaching fundamental skills which can be built upon during one’s career.

4. Case study: educational module of systems and user data from the Greater Toronto Area

4.1 Introduction
This case study presents an educational module that utilizes modern user and systems data to evaluate improvements in a public transit system. This study uses data from the Greater Toronto Area (GTA), but can be tailored to any region with access to Google Transit and local user data. In order to accurately represent the conditions in the GTA, several components are included so that proper evaluation of the system-demand interactions can be made: road networks; GO Transit regional rail and bus routes; Toronto Transit Commission (TTC) local transit: bus, streetcar, and subway routes; and user origin-destination (OD) trip data.

The process covered is fairly standard of any existing transportation planning course. We would have the student run through the data preparation for multiple components: the road network, transit networks, zones, and trip data. With the model prepared, analysis can be conducted and the results evaluated. If there is more than one scenario, those inputs can be changed and the analysis and evaluation can be conducted again. Each subsection includes labels
to provide educators with information relevant to data-driven changes: learning objectives of that subsection, learning curve to highlight the expected time to learn that material, knowledge prerequisites in order to learn the material within that time frame, and optional objectives depending on availability of additional data or modeling software.

4.2 Data gathering

Learning Objectives: GTFS data acquisition, OD demand data acquisition, network and zone shapefile acquisition

Learning Curve: 8 hours

Knowledge Prerequisites: research, urban planning sources

Optional Objectives: GPS trajectory feed, basic machine learning

For this case study, we use ArcGIS and TransCAD software. ArcGIS is a GIS platform for designing and managing solutions by applying geographic information (Esri, 2012). ArcGIS provides tools for performing spatial analysis, merging data, performing analytical operations, and creating accurate maps. TransCAD is a GIS-T software that can store, display, manage and analyze transportation data (Caliper, 2013).

User origin and destination trip data is obtained from the Transportation Tomorrow Survey (TTS), a travel survey conducted in the Greater Toronto and Hamilton Area. The TTS is jointly undertaken by agencies represented by the Transportation Information Steering Committee (DMG, 2008). Two datasets from the 2006 TTS were acquired. The first is a shapefile containing the activity zones in the GTA (DMG, 2008). The other is the trip data consisting of number of trips by origin and destination (DMG, 2009).

Public transit routes are a large component of the GTA model. Two GTFS files were required in this model for the two major transit agencies, one representing the TTC routes and the other representing the GO Transit routes. The GTFS files are accessible by anyone through the GTFS Data Exchange database (Google, 2012).

The road network file was provided by Statistics Canada and is a representation of the 2011 census year (Statistics Canada, 2011). The file consists of a shapefile and corresponding database file. The data from all of these sources were combined in TransCAD to create the basis of the region’s model representation.

This is the portion of the module where students can experiment with linking GIS data to other sources for continuous feeds, such as when GTFS data for the GTA transit systems get updated periodically. If mobile GPS data related to trips made are available, the user OD data can be compared against. If access to real time traffic conditions are available from a local traffic management centre (e.g. through ONE-ITS headed by the University of Toronto), then peak hour conditions can be sampled for several links to compare the base scenario against.

4.3 Greater Toronto Area model

To give some sense to the size and scale of the GTA, the 2011 census reveals a population of 5.8 million defined by the central city of Toronto and four regional municipalities: Durham, Halton, Peel, and York, and is the 5th largest metropolitan area in North America (Statistics Canada, 2011). It generates approximately $240 billion GDP (Invest Toronto, 2013). The process of modeling the GTA is similar to that of Spurr (2005), who constructed a model of the city of Montreal in order to test the impact of various policy options.
4.3.1 Defining zones and demand
Learning Objectives: user data integration: zone centroids, OD tables
Learning Curve: 6 hours
Knowledge Prerequisites: GIS shapefiles
Optional Objectives: activity based Monte Carlo simulation, user schedule-based activity routing estimation

The initial stage consists of establishing the zones and creating an OD matrix of the user trip data. There are 3,764 zones in the GTA shapefile which are imported. A centroid for each of these zones is created and an origin destination matrix must be assigned to them. The 2006 TTS data is used to create a matrix of trips where the origins and destinations correspond to the centroids. For the case study, only a single total transit trips was considered, although more detailed breakdown by trip purpose can also be done with available data.

If individual household travel survey data is available, it is possible to use that to help synthesize a population (e.g. Guo and Bhat, 2007) and corresponding activity routing system (Chow and Recker, 2012) for better understanding of schedule-based assignment methods and flexible transit alternatives. These disaggregate approaches can be aggregated to obtain an OD matrix to proceed to the next steps.

4.3.2 Road network layer
Learning Objectives: road system data integration: road sub-network extraction, calibration
Learning Curve: 4 hours
Knowledge Prerequisites: Network attributes, link performance functions

The first mode added to the network is the 2011 Census year Statistics Canada road network. The shapefile containing the road network data was imported into the model. This road network includes 1,973,932 links and 233,230 nodes which represent the majority of roads in Canada. Only a portion of the road network is used in the GTA model. The road network shapefile may not contain capacities or volume delay parameters, which would need to be calibrated. Actual calibration would take many hours to conduct, but for an educational module, simple assumptions can be made to assign values to parameters based on roadway type.

4.3.3 Transit network layers
Learning Objectives: transit system data integration: GTFS import, route/stop editing, connection to road network
Learning Curve: 10 hours
Knowledge Prerequisites: Network attributes
Optional Objectives: routing and scheduling

With the road network in place, the public transit routes must be added. The GO Transit and TTC GTFS files were imported into TransCAD, which incorporates the nodes, links, routes, transit stops, physical stops, and schedules into the model. The Transit routes were then verified and problem routes were removed. There are 1,359 GO Transit routes and 3,282 TTC routes. A total of 347 GO Transit routes and 163 TTC routes were removed from the model due to various issues such as: improper latitudes and longitudes, milepost referencing problems, and overlapping nodes. The software was not able to conduct a transit assignment unless these problem routes were removed. In order to analyze both the transit modes together, they had to be combined. This can be done by merging the route system files of both transit systems to create a combined layer.
Since the GTFS data includes schedules, it can also be used to support schedule-based analyses of household activities, as an extension of the optional objective in Section 4.3.1. Having an understanding of routing and scheduling principles would help this effort in preparation for schedule-based assignment or flexible route evaluation.

4.3.4 Network files

Learning Objectives: GIS visualization
Learning Curve: 4 hours
Knowledge Prerequisites: basics of GIS transportation planning software
Optional Objectives: real-time database feed

The final step in preparing the Greater Toronto Area model is creating the network files. A network file representing the road network is required when carrying out any assignments. The network file specifies which features of the line layer are included, which field represents the link length, and which link and node attributes are included in the network (Caliper, 2000).

Transit Networks in TransCAD are used for: solving best path problems, calculating attributes of the best path, and performing transit assignments (Caliper, 2002). Similar to road networks, transit networks are graphs consisting of nodes and links. These nodes and links indicate travel paths and costs of traversing each link. The following describes the process of creating the transit network, which can be extended to any region:

1. Transit stops were linked to the road layer using the tag stops tool.
2. The routes for inclusion in the network were selected.
3. Information from the line layer, route fields and stop fields were selected.
4. Walking links were created to and from the stops of both GO Transit and TTC routes.
5. Driving links were specified. Only the GO Transit route stops outside of Downtown Toronto allowed driving access as they provide vehicle parking.
6. The network was created and verified.

Figure 2a illustrates the Greater Toronto Area model. Optionally, interested students may be able setup a real-time update of data so that whenever the GTFS for the region is updated, one can open TransCAD (or respective software) to execute the update.

4.4 Trip assignment

Learning Objectives: transit assignment and network evaluation
Learning Curve: 16 hours
Knowledge Prerequisites: frequency-based transit assignment
Optional Objectives: flexible service assignment, schedule-based assignment, multimodal assignment

There are two categories of trip assignments, traffic and transit. A frequency-based transit assignment such as the optimal strategies method by Spiess and Florian (1989) can be conducted to determine volumes of passengers assigned to each transit route. This information can be used to consider trade-offs for evaluating sample investment alternatives to give the students a taste of scenario analysis using the model.

For considering flexible services (flex-route, car-sharing, ride-sharing, etc.), multimodal solutions (parking, shared-bike connectors, etc.) or schedule-based assignment, a GIS-T software would need to be able to simulate the scheduling choices of passengers so that they would be assigned to different schedule-based service. This is still very much an active research area, one that should benefit from the studies in activity routing (e.g. Kang et al., 2013).
Figure 2b illustrates the results of a stochastic user equilibrium transit assignment on the GTA model using the TTC transit network.

FIGURE 1 Road network, transit networks, and zones in the GTA model in TransCAD (a) and the results of a Transit Assignment using the TTC transit network (b)
4.5 Limitations
Several limitations regarding the modeling and analysis components were identified. Incorporating transit networks in the model is not very difficult when using GTFS files, however creating new routes can be very complicated. This makes the addition of new routes, especially flexible transit routes, very difficult. When conducting assignments, either a traffic or transit assignment can be selected. The user is unable to conduct both assignments simultaneously. Instead, a traffic assignment must be completed and specific results are used when conducting the transit assignment.

5. Final thoughts
The subject of transportation planning can take so many forms and span so many disciplines that defining the best topics to teach students can be challenging. Chow et al. (2013) suggest two distinct ‘tracks’ for masters students – one for those who will pursue a career in professional practice, and another for those on the path to doctoral studies and research – bound by a common set of fundamental courses. This paper, however, is focused on preparing practitioners and lowering the barrier between transit developments in academia and in practice. It is important to remember that in a subject such as transportation which, as well as already being a broad subject, is rapidly changing and expanding, that the fundamentals are not necessarily the same as what they were in the past, whether that fact has been widely recognized or not. Guihaire and Hao (2008) report that publications in transit network design in recent years focus on heuristic and metaheuristic methods. This is opposed to older papers which focus on solutions by known mathematical models; these are situation-specific and allow little flexibility. The MILATRAS simulation model developed at the University of Toronto is a good example of these ‘new fundamentals’. Its application by Wahba and Shalaby (2011) is representative of the new skills needed by transit professionals: transit data sources, geographic data and GIS-T, learning-based simulation.

Consider the business model of transport systems. Wang and Schiavone (2012) present the benefit of continuing education for professionals in the transportation field in the context of a Return on Investment – being the funds spent on the education program. The results were supportive of such education programs. The benefit of improving students’ education programs then is twofold: 1) the skills and knowledge brought to an agency, and 2) an easement on the necessity for training in modern topics, especially when transit agencies in the United States spend, as a percentage of payrolls, 0.66 - 0.88%, whereas the national average is 2% (Wang and Schiavone, 2012).

Equally as important as specific fundamentals is teaching how to adapt to new technologies and developments or changes in the way existing technologies are used (Dietz, 1995). The advent of Big Data in transportation data sources is one such development. Analytics of Big Data are shown to be the mark of a successful business model (LaValle, 2011) and new technologies in transportation are proving their effectiveness for travelers the world over. As such, modern curricula should consider ‘new fundamentals’ that better reflect the state and the future of transit planning.

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