TRANSIT USER BEHAVIOUR IN RESPONSE TO SUBWAY SERVICE DISRUPTION

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ABSTRACT

Disruption of transit service is a common occurrence in many cities around the world, and these incidents may have serious impacts on the transit user’s journey. Transit user behavioural response under disrupted service conditions, specifically how transit riders choose among available mode options to complete their trips, is not well understood. Mode choice studies often lack proper consideration of travel time variability and uncertainty in such situations, neither do they fully account for some options considered by users, such as waiting, taking a shuttle bus, or cancelling the trip. This study aims to investigate transit user mode choice in response to peak hour rapid transit service disruption in the City of Toronto, incorporating such factors as the type of disruption, stage of the passenger’s trip (pre-trip or en-route), weather conditions, and uncertainty of delay duration. A joint Revealed Preference (RP) and Stated Preference (SP) survey is designed where the RP part gathers information on the respondent’s actual response to the most recent service disruption while the SP part solicits the respondent’s responses under a set of hypothetical service disruption scenarios. A transit trip planner tool is developed to generate alternative transit mode and path options to avoid the disrupted segment. The survey methodology is discussed including the scope, experimental design, survey sample design, survey instrument design, and survey implementation. The data collected would be used to develop econometric models to understand the potential effects of different factors on the choice making behaviour of transit users under conditions of service interruption.

Keywords: public transit, service disruption, travel behaviour, mode choice, RP-SP survey

1. INTRODUCTION

Disruption of public transit service is a common occurrence in many cities around the globe. Disruptions can range from a breakdown of a single bus to the shutdown of entire subway lines over an extended period of time, and these incidents have huge impacts on passengers’ journeys. The underlying causes can be numerous including external factors such as weather, accidents, security issues, power outage or internal such as crew shortage, breakdown of transit vehicles or infrastructure. Depending on the nature and severity of these disruptions, passengers are likely to have different behavioural responses to different types of disruptions.

Many transit agencies have established practices to respond to service disruptions, and there exist many studies on service recovery and management measures. However, the effects of these disruptions and response strategies on transit user behaviour is not well understood (Papangelis, et al., 2013). For the few disruption studies that consider transit user behaviour, they were usually based on logical assumptions instead of empirically measured behaviour. Similarly, performance indicators which are widely used in the transit industry are usually operator oriented and less passenger oriented (Barron et al., 2013), for example focusing on train delay instead of passenger delay. Furthermore, some disruption studies are sometimes event driven and conducted due to a major disruption; therefore they have limited ability to draw more generalized conclusions.

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Transit user behaviour is significantly different in the event of service disruptions, which may have significant impacts on the passengers’ experience. User responses and behavioural changes can vary according to the stage of the trip at the time of service disruption. For example, a passenger finding out about a transit service disruption before starting the trip (pre-trip) may make no changes (travel on the same route), switch mode or route, or even cancel the trip. A passenger encountering a transit service disruption during the trip (en-route) may decide to catch the replacement shuttle buses (if applicable), walk to the destination, take a cab, or wait until the disruption is over. The passenger can make different choices based on the information provided and its timeliness with respect to the disruption event. After experiencing a trip involving service disruption, a passenger making a similar trip in the near term (post-trip short-term) may decide to change the departure time or try a different route or mode. After encountering multiple service disruptions over a long period of time (post-trip long-term), a passenger may decide to permanently adjust the departure time, switch away from this route or mode, change destination, cancel trip, or make no changes; it is also possible to see more drastic changes such as household location or car ownership.

The passenger experience and behaviour can also differ based on the causes of disruptions. For example, disruptions caused by the transit agencies are likely to be more frustrating and unacceptable for the passengers; on the other hand, crime or terrorism related incidents can be more frightening and have longer effects on passengers’ behaviour. In addition, there are some pre-announced disruptions such as pre-planned closure for maintenance and upgrade as well as labour strike. These instances are also expected to induce different responses than unexpected incidents as travellers can obtain information about the closure and consider alternative choices before their trips. There are other factors that can also affect the passenger behavioural changes, such as the length of delay, presence and media of information provision, timeliness and accuracy of provided information, and other level of service considerations (such as safety, comfort, reliability) of various alternative modes. These considerations demonstrate that passenger responses and adaptations are extremely complex, requiring a more thorough investigation.

The main purpose of this research is to understand the travel behaviour of transit users in response to service disruptions in order to capture the behavioural responses in the time frames of interest. The pre-trip and en-route time periods are characterized by short or no notice, with or without relevant information when passengers have to make a decision quickly for a single trip about to start or already started. Post-trip short-term and post-trip long-term time periods do not necessarily have a well-defined time periods and are concerned with behavioural adaptations through learning and experience over time that lead to more permanent changes. Due to the differences between immediate single-journey responses versus longer-term permanent changes, as well as the more complex decision making and factors involved in longer term behavioural adaptations, this paper is focused on the immediate response behaviour of transit users following service disruption (i.e. pre-trip and en-route response). The study aims to review the current literature on passenger behaviour in response to disruptions, identify the shortcomings of the existing literature, and propose a conceptual framework to outline the approach and methodology.

2. LITERATURE REVIEW

2.1 Disruption Types

Given that different types of disruptions can result in different passenger behavioural responses and adaptations, it is important to classify the disruptions by type of cause. Transit disruptions can generally be classified into the following four categories of causes: natural, human accidental, human intentional, and operating environment. These categories can each be subdivided, if applicable, into external causes and internal causes. External causes are instances where the transit agency has no control and the cause of incident is not related to the transit personnel or properties, while internal causes are those with some level of transit agency involvement. Given that the geographic scope of this study is the City of Toronto with emphasis on rapid transit, the 2013 TTC (Toronto Transit Commission, the local transit agency of Toronto) subway incident report was referenced to obtain the frequency and duration of each type of disruption. The incidents with delays less than 10 minutes were considered minor incidents related to recurring reliability issues and thus were not included in the analysis while incidents with a 10-minute delay or longer, 627 recorded in 2013, were considered as major incidents (or simply referred to as incidents henceforth) or disruptions. Table 1 builds on the classification by Nielsen (2011) and summarizes the types of disruptions by cause and the likely consequences with relation to transit service, while Table 2 provides the incident frequencies and durations in the TTC rapid transit system in 2013.
Table 1: Taxonomy of Disruption Causes and Consequences

<table>
<thead>
<tr>
<th>Causes</th>
<th>External</th>
<th>Internal</th>
<th>Causes</th>
<th>Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>[length of suspension, damages to transit properties]</td>
<td>[length of suspension, damages to transit properties]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural (Weather)</td>
<td>I. Hurricanes, thunderstorms, flooding</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>II. Blizzards, heavy snow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>III. Extreme temperature</td>
<td></td>
<td></td>
<td>[medium to long term, yes]</td>
</tr>
<tr>
<td>Human Accidental (collisions, passengers and operators issues)</td>
<td>I. Medical issues, passenger assistance required</td>
<td>I. Fire</td>
<td>II. False alarms</td>
<td>II. Operator error</td>
</tr>
<tr>
<td></td>
<td>III. Collisions (external party involved)</td>
<td>III. Crew illness or availability issues</td>
<td></td>
<td>IV. Collisions</td>
</tr>
<tr>
<td>Human Intentional (crime related, labour strike, maintenance)</td>
<td>I. Security issues and terrorist attack</td>
<td>I. Pre-announced or last-minute announcement of labour strike</td>
<td>II. Vandalism</td>
<td>II. Pre-announced maintenance or upgrade</td>
</tr>
<tr>
<td></td>
<td>III. Suicide attempt</td>
<td></td>
<td></td>
<td>IV. Disorderly patron and assault</td>
</tr>
<tr>
<td></td>
<td>IV. Disorderly patron and assault</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Environment (outage, breakdown)</td>
<td>I. Power outage</td>
<td>I. Breakdown of infrastructure or rolling stock</td>
<td>II. Communication (internet, signal) outage</td>
<td>II. Unreliable or unsafe to operate</td>
</tr>
<tr>
<td></td>
<td>[short to long term, usually no]</td>
<td></td>
<td></td>
<td>[temporary to medium term, yes]</td>
</tr>
</tbody>
</table>

Table 2: Summary of 2013 TTC subway incidents statistics

<table>
<thead>
<tr>
<th>External</th>
<th>Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total incidents</td>
<td>Average Delay (minutes)</td>
</tr>
<tr>
<td>Natural</td>
<td>7</td>
</tr>
<tr>
<td>Human Accidental</td>
<td>191</td>
</tr>
<tr>
<td>Human Intentional</td>
<td>135</td>
</tr>
<tr>
<td>Operating Environment</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>334</td>
</tr>
</tbody>
</table>

Not surprisingly, natural causes of incidents, while rare, had the longest delays. Accidents accounted for the majority of all 2013 subway incidents, at 56%. Approximately half of those were external, mostly due to passenger illness or injury, while the other half were internal, predominately due to fire related. The average durations of delay for external and internal accidents, however, were the smallest as the incidents are usually local and not malicious. External incidents were mostly disorderly passengers (shorter delay) and security issues (longer delay). There were no instances of pre-planned closure during the time periods of interest (peak periods). The operating environment causes can be breakdowns of infrastructure, rolling stock or other transit properties, such as signal, train, track, power, door, and mechanical; among those, signal issues had substantially longer delays.

2.2 Transit User Behaviour

The studies done on passenger behaviour in response to transit disruptions consider a general disruption or a specific type of disruption. Studies on a general disruption look at service suspension without particular a cause. Studies on a specific type of transit disruption mainly focused on a particular event or incident that typically had large impacts immediately after the incident and possibly in the long term. Due to their specific nature, the findings may only be applicable to a particular type of disruption, geographical area, or only the incident itself if it is very unique.

Fukasawa et al. (2012) conducted a stated preference (SP) survey on passenger behaviour in response to an en-route disruption to compare their departure time and level of service (local vs. express) choices between scenarios with and
without information provision of estimated travel time and crowding. The study found that there would be more instances of switching to other trains if information on alternative options was provided and that passengers prefer having some information about the delays even if it is not always accurate. Bai & Kattan (2014) also conducted an SP survey to study the effect of information provision on the passengers’ en-route mode choice given LRT delays and found that a significant mode and transit mode shift would occur (over half) when information on the length of delay is not provided, compared to less than 25% with length of delay given and not too long (10 minutes).

All but one study looked at a specific type of disruption without focusing on a single event: Lu et al. (2014) investigated the impacts of flooding as a possible recurrent event by conducting an SP survey on traveller behaviour in extreme weather events that can lead to flooding and found that 70% of travellers (among different modes) would alter their travel behaviour in the form of departure time, mode, destination, and trip cancellation. The study showed that in certain situations, extreme weather events might be perceived as recurrent and not unexpected, thus inducing long term behavioural adaptation in travel.

Studies that focused on a specific event of disruption mostly collected revealed preference (RP) data after the incident. The New Zealand Ministry of Transport (2013) conducted a study following the storm that resulted in a 6-day partial closure of one commuter rail line and found substantial short-term changes in rail mode share for the area served by this rail line from 51% to 22% (the latter using rail and replacement bus). The study also showed that 11% of riders changed their departure time or mode in the long term, but the agency drew the conclusion that long-term changes were not observed as a result of the storm. Murray-Tuite et al. (2014) studied the behavioural changes due to a fatal rapid transit accident in Washington DC and observed that 17% of Metrorail users avoided the front or rear car of the train while 10% switched to a different transit mode or travel mode. The study did not explicitly mention the focus on short-term or long-term behavioural changes and it acknowledged the sampling bias by not collecting data from passengers who no longer took transit. Pnevmatikou & Karlaftis (2011) conducted an RP study on transit users’ mode and route choice after the re-opening of an Athens Metro Line from a 5-month pre-announced closure. The results showed that 58% of the respondents continued with the same transit mode (metro) or replacement bus service and 76% continued to use transit while only 9% switched to modes involving auto despite significant service delays. The study also excluded riders who no longer take the metro line. Pnevmatikou et al. (2015) then combined this study with an SP study from different respondents during a series of planned strikes and found that the joint RP-SP estimation with Nested Logit model performed better. The SP study only considered three options (auto, bus, and taxi) for investigating behavioural changes. Van Exel and Rietveld (2009) conducted a case study on the pre-planned and pre-announced one-day rail strike in the Netherlands in 2004 and found that 44% who intended to travel by rail cancelled their trips, while almost half of those who intended to travel by car also changed their behaviour (e.g.switching mode or cancelling trip) in anticipation of transit network disruption. The study did a before (SP) and after (RP) comparison and found that 86% of respondents had the same behaviour as their stated choice beforehand.

### 2.3 Survey Methods

The two main types of passenger travel surveys are revealed preference (RP) and stated preference (SP) surveys. Traditionally, RP surveys collect data from a sample of respondents on trips they have made in a previous time period (e.g. the previous day). The stated preference approach was conceived in the 1960’s, with applications starting in 1970’s in market research (Green & Srinivasan, 1978; Kroes & Sheldon, 1988). SP data capture the preferences and choices of respondents when presented with hypothetical scenarios of various travel options or policies that may or may not be available in the real-world transportation system at the time of the survey.  

The SP approach has recently gained more traction due to several disadvantages of RP data, including limited data variation, treatment of strong correlation of variables, limitations in evaluating hypothetical conditions, and limitation on subjective variables (Kroes & Sheldon, 1988). First, RP data are limited to observations only and can have insufficient number and variation of the variables within the collected data to conduct insightful analysis on the effects of different variables. Second, the variables considered may be strongly correlated, such as travel time and cost, and it is hard to capture the effect of each variable and the trade-off in between from RP. Third, RP data are based on observations and thus cannot be used to evaluate hypothetical scenarios. Fourth, RP data usually include objective and quantifiable measures of variables, such as travel cost and time, and the evaluation of other qualitative variables, such as comfort and convenience, is difficult due to subjectivity. SP, on the other hand, can incorporate these subjective variables by quantifying them (e.g. crowding level for comfort). In the context of transit user behaviour under conditions of service disruption, behavioural investigations are hard to conduct using RP surveys due to limited data.
RP surveys also tend to target transit users who continue to use the service without behavioural changes and thus the sampling frame excludes respondents who already switched transit route, transit mode, travel mode, or made other behavioural changes.

However, SP data also have limitations. The main issue of SP is the inherent bias or inaccuracy of the collected data, as the respondents might not actually choose the option selected in the SP survey in real life. This issue can be more prominent in situations where it is difficult for respondents to understand the hypothetical scenarios, such as creating and describing scenarios that induce long-term transit user behavioural adaptation. SP data are also subject to other biases such as policy bias and justification bias (Ben-Akiva & Morikawa, 1990; Kroes & Sheldon, 1988).

Due to the issues with RP and SP data mentioned above, studies have been done to compare between RP and SP data. Ben-Akiva & Morikawa (1990) compared model estimations using RP only, SP only, and joint RP-SP and found that the joint model had more accurate parameter estimates. The study demonstrated that combining RP and SP together can address the limitations of each type while utilizing the strengths of both. While the RP-SP approach has overcome the issues of RP and SP respectively and has become more widely used, the authors are not aware of any joint RP-SP survey done on behavioural studies or choice modelling for transit disruptions. Pnevmatikou et al. (2015) had a joint RP-SP estimation between two datasets from different incident type and respondents, which investigated short-term and long-term behaviours on two single-event pre-planned disruptions.

2.4 SP Experimental Design

There are two main types of SP experimental design: full factorial design, where all possible choice situations (all combinations of different attribute levels of all variables) are included, and fractional factorial design, where only a subset of the full factorial design is included (ChoiceMetrics, 2014). Full factorial design is usually not feasible due to the large number of choice situations and sometimes not reasonable in terms of certain combinations of attribute levels. The three main types of fractional factorial design are random, orthogonal, and efficient. Random design selects choice situations randomly and can lead to biased results due to unbalanced attributes. Orthogonal design requires a balancing of attribute levels and measures the independent effects of each variable. It has been widely used due to the historical impetus from the lack of studies to evaluate different design methods and the widespread use of linear models in the past that is more suitable for orthogonal design (Bliemer & Rose, 2011). Efficient design tries to minimize the standard errors for parameter estimates by using prior estimates that can be obtained from similar studies or a pilot study.

The efficient design, in theory, should perform better than orthogonal design or at worst perform equally well with orthogonal design if no prior information can be obtained. Recent studies have shown that the efficient design outperforms orthogonal design in empirical studies (Bliemer & Rose, 2011; Rose et al., 2008). Therefore, the efficient design is the preferred method, and obtaining prior estimates to construct efficient design would be crucial to ensure improvements over orthogonal design.

3. SURVEY DESIGN

3.1 Data Needs

Transit user behaviour during a disruption can be significantly different from routine travel depending on the circumstances, availability of choices, and the level of service of various choices. The primary mode choice can become unavailable due to a service disruption while sometimes alternative choices may become available (such as replacement shuttle bus service), feasible (such as walking to destination), or considered (such as taking a cab). The level of service attributes including travel time, travel time variation, information provision, comfort, and other factors can also vary greatly and can be perceived differently. Therefore, it is important to consider transit user behaviour under conditions of service disruptions separately from their behaviour under normal conditions, in order to capture the actual decision making and trade-offs. Traditional household travel surveys do not capture travel patterns under disruption conditions; neither do customer satisfaction surveys by travel agencies have details on incidents and how customers respond to service disruptions. Therefore, available survey data provide very limited information for this study and there is a clear need to collect specific data to better understand the user behaviour during service disruptions.
3.2 Survey Study Area

The survey study area is the City of Toronto, the largest city in Canada with the largest transit system (TTC) in the country and third largest in North America. The rapid transit system of Toronto includes two major subway lines, a third short subway line and an intermediate capacity rail line. This study focuses on rapid transit trips, which are trips involving at least one rapid transit segment within the City of Toronto, as rapid transit is the mode subject to the highest potential impacts. For this study, rapid transit trips include only rail transit with exclusive right-of-way operations because the isolation of the rail transit line makes the system unique in terms of disruption causes, recovery, alternative options for transit users, and the accessibility of those alternative options. For example, a bus rapid transit vehicle that breaks down can be removed more easily with minimal impact to subsequent services while a malfunctioning train can shut down part or all of the subway line for long periods, affecting an order of magnitude more passengers. Peak periods are the most sensitive and vulnerable times for disruption events, as travel demand and passenger volumes are the highest. Consequently, peak periods are characterized by tightly scheduled headway and high level of crowding, which lead to less buffer time and more difficulty to recover from delays and disruptions. Therefore, this study will focus on the peak periods (AM peak) to examine the transit user behaviour.

3.3 Survey Scope

This study only considers the pre-trip and en-route behavioural responses. In order to investigate the immediate passenger behaviour in response to disruptions, the types of responses must first be identified. For an en-route disruption, Bai and Kattan (2014) included the following options for the respondents: switch to driving or taxi (mode switch), take a bus (transit mode switch), walk and take the same LRT line at a different station (walk access to the same mode), do something while waiting (productive waiting), just wait (unproductive waiting or no change), and other. To remove the specificity of the transit mode and study area, the following generalized choices will be included for both pre-trip and en-route scenarios: auto mode switch (drive or taxi), route switch (different path using transit), replacement service (service provided specifically due to disruption, e.g. shuttle buses), cycling, walking, waiting (no change), trip cancellation.

There are three restrictions on modal feasibility, affecting the number of alternatives available to a user. These include the availability of the cycling mode only for pre-trip disruptions with non-zero household bike ownership, availability of cycling only if the trip distance is less than 15 km, and availability of walking only if the distance is less than 5 km. The threshold distances for cycling and walking are higher than the usual ranges of acceptable distances with journeys possibly taking up to an hour to complete; however, respondents should not be restricted from selecting a desired mode in a special circumstance if it is justifiable and there are several factors that make cycling and walking more attractive in this situation, including lowest variability of travel time, no wait time, no availability or crowding issues. Taxi is included in the auto mode option, so possession of a driver’s license or a vehicle is not required for this alternative.

3.4 Survey Experimental Design

The main advantage of SP data over RP data is the ability to capture choice behaviours in hypothetical scenarios that are difficult or impossible to obtain from RP data. The SP experiment includes different attributes and levels of potentially influential characteristics and factors to study the effects of each attribute on the individual’s choice making. Given the importance of capturing all effects of the numerous attributes and the importance of minimizing survey length to avoid fatigue and inaccurate responses, D-efficient design will be used for the SP experiment. D-efficient design requires prior estimates of attribute parameters from similar studies or a pilot study. Since no comparable study can be found for the initial estimates of the parameters, a pilot survey would be developed and conducted among the same target population as the main survey.

3.5 Survey Sample Design

The target population is defined as all rapid transit commuting workers and students 18 years or older in the GTA. According to the Transportation Tomorrow Survey (TTS) conducted every 5 years on household travel of 5% of the population, the total rapid transit commuters with trip origins and destinations in the City of Toronto come to around 760,000. The initial estimate of the sample size required for a margin of error of 0.05 and 95% confidence interval based on simple random sampling and adjusted for population size is 384. However, the sample size required for the survey also depends on the requirements of the D-efficient design for the SP section. The sample size for the pilot can

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be small as it is used for obtaining prior parameter estimates to carry out the D-efficient design and has been chosen to be 50. The sample size for the main survey needs to be determined upon completion of the final experimental design and is likely to be higher than 384. Once the sample size of the main survey is determined, the percent of residents commuting using the subway (qualification), estimated survey response rate and survey completion rate would be used to estimate the number of survey invitations needed for the required sample size.

3.6 Survey Instrument Design

The joint RP-SP survey consists of three main sections: RP, SP, and socio-economic information. In Section A, the RP component collects information on the individual’s last encounter of service disruption, the choice made during the disruption and the relevant information for the trip. In Section B, the SP component presents hypothetical scenarios of service disruptions by providing various attributes and levels of travel mode alternatives to the respondent to obtain his or her stated choices and the effects of individual variables on the choices made. In Section C, background and socio-economic information is collected at the end to analyze the demographics and its representativeness of the population. The survey data model is presented in Figure 1.

3.6.1 Trip Planner Tool

The survey provides hypothetical scenarios reflective of the respondent’s usual commute by customizing the trip using the origin-destination (OD) pair of the respondent’s regular commute. The attributes for these scenarios can be specified by either constructing a trip planner tool that can compute alternative routes online or looking up the level of service attributes for a particular OD zone pair from a pre-calculated attribute table. The trip planner is more accurate and reflective of the respondent’s actual OD pair but requires extensive design and testing of the trip planning application as well as online computation of all the required trip attributes for each alternative. On the other hand, the lookup table allows computation of all required attributes offline at a zonal aggregate level for each mode without providing the route using a network assignment model. Based on the trade-offs between complexity, computation efficiency and accuracy, both methods are utilized. The auto travel time and cost is based on the EMME network assignment model using 2011 trip data and 2012 network model. The access, egress, in-vehicle time, transfer time, and number of transfers are calculated for all choices involving transit using the trip planner to enable generation of multiple routes. Cycling and walking distance is calculated offline using GPS coordinates.

Google Directions API (application programming interface) was used to construct the mode and route alternatives for the customized trip planner tool. While Google API allows for obtaining mode specific travel times, it cannot be instructed to remove or block a specific segment of the subway line to represent a transit service disruption scenario. This was found to be problematic because the best alternative route often times involves using the subway in the non-disrupted section. The trip planner tool was later modified so the API would be used for surface transit only and the subway travel time and transfers was pre-calculated offline using GTFS (General Transit Feed Specification) data for each pair of subway stations to provide realistic and competitive options to get to the destination.

3.6.2 Revealed Preference

In Section A, the following information is collected regarding the respondent’s last encounter of subway service disruption: origin and destination of trip, TTC subway access station, access mode, egress station, egress mode, number of subway/LRT transfers, date and time of last disruption encounter, location (subway station), type, and duration of incident, purpose of trip, departure time, expected arrival time, parking cost at destination, weather condition, information provided pre-trip and en-route, availability of replacement bus service, chosen alternative, confidence level of choice at time of choice, confidence level of choice at trip completion (retrospective evaluation), additional travel time, additional travel cost, possession of a driver’s license, household bike and auto ownership. The Google Maps API (application programming interface) is used for the respondents to enter the origin and destination of the trip so it can be Geocoded based on a variety of inputs (address, postal code, name of place).

3.6.3 Stated Preference

The attributes to be included in the survey are various factors that can influence passenger behaviour. There are many variables of interest and relevance but only the 10 most important attributes were selected to be varied in the survey to limit the length of the survey. In order to minimize the total number of possible scenarios, all but two of the attributes have only two levels, which are deemed sufficient to distinguish among different circumstances. The only exceptions
are the disruption type by cause where the top three incident categories were included to avoid generalization between distinct characteristics among each category. The list of disruption types are discussed in the following paragraph and the list of all other attributes and their levels are summarized in 3.

Section A: Revealed Preference

Google Maps tool

Origin

TTC subway access mode
-Access time
-Wait time

TTC subway access station
-No. of transfers

TTC subway egress
-Transfer time

TTC subway egress mode
-Egress time

Destination

-Parking cost
-at destination

-In-vehicle travel time

Transit Service disruption

Information
-Date
-Time
-Location (subway station)
-Incident type
-Incident duration
-Shuttle bus availability
-Weather

Behaviour
-Mode chosen
-Additional travel time
-Additional travel cost
-Confidence level at time of choice
-Confidence level at end of trip

Household
-No. of vehicles
-No. of bikes

Individual
-Driver’s license
-Transit pass

Trip
-Trip type
-Departure time
-Expected arrival time

Figure 1: Data Model

Section B: Stated Preference

Incident generation
-Location generation
-Subway incident data

LOS generation
-Trip planner tool:
-Google Directions API
-EMME auto LOS
-GTFS
-auto and bike availability

D-efficient design

Feasible choice set generation

Choice Scenarios
-7 scenarios, with customized trip origin and destination provided with varying LOS and other attributes, to make a mode choice in each

Consideration choice set

Section C: Socio-economic Information

Socioeconomic information

Personal
-Age
-Gender
-Highest level of education
-Employment type

Household
-Dwelling type
-Home tenure status
-Household size
-Household income
Table 3: Summary of SP attributes and levels

<table>
<thead>
<tr>
<th>Attribute name</th>
<th>First level</th>
<th>Second level</th>
<th>Third level</th>
<th>Fourth level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage of trip</td>
<td>Pre-trip disruption</td>
<td>En-route disruption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather condition</td>
<td>Comfortable</td>
<td>Not comfortable</td>
<td>(heat, cold, snow, extreme temp)</td>
<td></td>
</tr>
<tr>
<td>Incident type</td>
<td>No information</td>
<td>Signal or train problem</td>
<td>Medical emergency</td>
<td>Fire investigation</td>
</tr>
<tr>
<td>Delay information on subway</td>
<td>Unavailable</td>
<td>Available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of delay or wait time (subway)</td>
<td>Medium (30 minutes)</td>
<td>Long (60 minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy of delay duration (subway)</td>
<td>Small (0 to +10 minutes)</td>
<td>Large (0 to +30 minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay information on replacement shuttle</td>
<td>Unavailable</td>
<td>Available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of delay or wait time (shuttle)</td>
<td>Medium (10 minutes)</td>
<td>Long (20 minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy of delay duration (shuttle)</td>
<td>Small (0 to +10 minutes)</td>
<td>Large (0 to +30 minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto cost [3]</td>
<td>Pre-trip normal $0</td>
<td>En-route low (-25%)</td>
<td>En-route normal $2.9</td>
<td></td>
</tr>
<tr>
<td>Transit cost [4]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


The following types of disruption will be considered in the survey: breakdowns of subway infrastructure or fleet (with signal and train problems being the most frequent), medical emergencies (caused by passenger illness, contact with train or other injuries), and fire investigations (mostly smoke or odour of smoke at track or on platform). The other types of disruptions occur less frequently and have been excluded. There is also an additional level for the lack of information on the disruption type to represent situations when passengers are not given a reason.

A hypothetical disruption event needs to be created before the SP experiment can be constructed. The location of disruption would be randomly generated from the list of subway stations that the respondent passes by based on the relative probability (frequency) of incident occurrence at each station in the 2013 incident report. Once the location (subway station) of the disruption is determined, which would remain the same for each respondent throughout the survey, the segment of the subway line that would be closed can be determined based on track cross-over location and the “new” origin of the en-route disruption scenario can be presented (while the pre-trip origin remains the same) along with the level of service attributes for the respondent. The SP scenarios would be created by changing the attribute levels of different variables based on D-efficient design using the Ngene software (ChoiceMetrics, 2014). Each respondent would be presented with seven scenarios with up to seven alternatives and would make a mode choice for each of the scenarios as well as indicate a confidence level for each choice. Upon completion of the last scenario, the respondent would be asked to identify the alternatives considered in the presented choice set because the respondent might not consider all possible alternatives provided in the choice set.

3.6.4 Demographic Information

The socio-economic information includes those pertaining to the individual and his/her household. Household information includes dwelling type, home tenure status, household size, and household income. Individual information includes age, gender, highest level of education, and employment type.

3.7 Survey Implementation

The data collection is taking place in the winter of 2016 with the help of a market research company. The survey has been approved by the Research Ethics Board of the University of Toronto and is ready to be tested in terms of its interface, layout, questionnaire quality and clarity. Once testing is concluded, a market research company will recruit respondents and distribute the survey. Respondents would be randomly selected from a panel of survey participants.
who previously agreed to be contacted and invitations to the online survey would be sent by email. The final survey would be conducted in the same manner after incorporating the pilot survey results for parameter estimates and survey improvement from feedback.

4. CONCLUSION

This study aims to investigate transit user behaviour in response to service disruptions before and during a morning AM peak trip. The literature of behavioural studies on transit disruptions is reviewed to understand the current practices and methodologies. A summary of the types of transit service disruptions and the local transit subway incident report is provided to present the incident classification and local context with regards to transit service disruptions. The data requirement for a joint RP-SP survey is discussed and details regarding the survey are provided. The next step is to collect data and to develop econometric models to understand the individual effects of different factors that influence the choice making behaviour of transit users.

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