CONTINUOUS DATA COLLECTION APPROACHES FOR HOUSEHOLD TRAVEL SURVEYS

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Transportation Tomorrow Survey 2.0

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1 INTRODUCTION

A cross-sectional survey is defined as a survey executed at a point in time and conducted on a one-off basis (Miller, et al., 2012). Large regional household travel surveys, while typically conducted over weeks or months, are still considered cross-sectional, as the data are pooled to represent a "typical day" (Miller, et al., 2012). The Transportation Tomorrow Survey (TTS), conducted in the Greater Toronto and Hamilton Area (GTHA) and repeated every 5 years, falls under this category. It is a multi-objective repeated cross-sectional survey with the general aim of understanding travel behaviour trends in the GTHA and predicting future trends to aid in implementing municipality-specific and region-wide transportation policies.

The first TTS was conducted in 1986, sampling 4.2% of the general population of the Greater Toronto Area (Data Management Group, 2013). Since then, the survey has been conducted every 5 years, maintaining a 4%-to-5% sampling rate (with the exception of TTS 1991), while keeping it cross-sectional in nature. Although the TTS has served the GTHA relatively well over the past few decades, this cross-sectional nature of the survey has had its limitations. Key issues have included that only one weekday has been surveyed for all households in the sample, and the cost of ramping up every five years to conduct such a large scale survey has been substantial. As a results, there has been interest in the potential of replacing the regional cross-sectional survey with one of a continuous nature.

The objective of this report is to explore the feasibility of a continuous survey method as an alternative to the cross-sectional TTS. The report is structured as follows: Section 2 introduces the concept of a continuous survey, along with its potential applications. It also presents a comparison between continuous surveys and cross-sectional surveys, as well as the distinction between a continuous and a panel survey. Section 3 discusses the methods found in literature for the weighting, expansion and validation of continuous data. Section 4 presents a discussion on two major regional continuous survey experiments in Montreal, Canada and Sydney, Australia. Section 5 presents an investigation into the statistical methods needed to construct point-in-time estimates of traffic zone-level O-D trip matrices from continuous data "streams". Section 6 provides a brief assessment of the various data collection tools, along with a brief note on the compatibility of such tools with a continuous survey approach. Finally, section 7 concludes the report with the next steps and potential pilot tests for assessing the applicability of a continuous survey method to collect data for the GTHA. Key terms of survey types used throughout the report are detailed in Table 1 below.

TABLE 1: GLOSSARY OF TERMS USED

Survey Type	Definition
Cross-Sectional	One-off survey executed at a point in time
Repeated Cross-Sectional	Survey repeated at set time intervals while sampling different persons/households at each wave
Continuous	An ongoing repeated cross-sectional survey where sampling time intervals are in very close proximity – usually a day
Panel	A set group of individuals/households are repeatedly sampled over an, preferably, elongated time period

2 BASICS OF CONTINUOUS SURVEYS

In a full on-going continuous survey, data are collected for an entire weekday, every day of the week, 52 weeks a year (Ortuzar, et al., 2010). Such effort should ideally be kept going for several years. These data, collected over a large period of time, can potentially be used to observe temporal trends in travel patterns and behaviour at an aggregate level in the survey area. The idea of using a continuous survey for collecting travel demand data are not new. As far back as the 1960s, Kish advocated for splitting a large cross-sectional survey into smaller repeated surveys with a relatively small interval time period (Kish, 1965).

Several European countries have adopted continuous surveys to monitor country-level travel behaviour over time. Examples include the French rolling census initiated in 2004 (National Institute of Statistics and Economic Studies, 2004), and the Netherland National Mobility Survey (NNMS) in the Netherlands. The NMS was started in the Netherlands in 1978 and it is one of the oldest and longest standing continuous surveys. A third example is the National Travel Survey (NTS) in England, Scotland and Wales, which has been going on since 1988. The NNMS is a landline-based survey, while respondents are surveyed face-to-face in the NTS. Furthermore, several other continuous surveys are conducted on a regional level in other locations, such as the Sydney Household Travel Survey (HTS), and the experimental continuous survey conducted in Montreal. These region-wide surveys will be discussed in more detail later on in the report.

Tables 2 and 3 provide a summary of a number of continuous surveys conducted over the last forty to fifty years. The original version of these table are found in (Ortuzar, et al., 2010). As can be seen in table 2, most continuous surveys collect 1-day trip diaries from the respondents. Ongoing region-wide continuous surveys of this nature can be found mostly in Germany, Austria and Australia. As opposed to one-day surveys, a number of multi-day per respondent (panel) surveys are also evident, such as the Great Britain National Travel Survey, where survey respondents completed week-long trip diaries. A week-long trip diary can greatly reduce the sample size required to accurately depict travel behaviour within a pre-specified area. Specifically, Stopher et al. (2008) estimated that a week-long GPS survey could lead to a 35% reduction of sample size as compared to a one-day survey (Stopher, et al., 2008).

Table 3 presents the sample size and response rates of a number of continuous surveys. Santiago de Chile, Sydney and Montreal have adopted a sampling rate of 1% per year. The response rate of the region-wide continuous surveys has averaged approximately 61%, with a minimum of 25% (2002, Melbourne) and a maximum of 87% in Nuremburg. Nonetheless, an interesting observation is the high response rates experienced in Austria and Germany. This is primarily due to the implementation of the New Kontiv diary design which allows respondents to report their out-of-home activities for a pre-specified day using their own words (Ampt & Ortuzar, 2011). This is in contrast to the current TTS survey where the questions and answer options are pre-specified for the respondents.

All region-wide surveys to date, with the exception of Montreal, have relied on some form of human interaction to collect data from respondents. In Australia, face-to-face interviews are the mode of choice, where survey respondents are visited twice by an interviewer. During the initial visit, the interviewer fills the household information of the respondents and hands them the trip diary to be completed for a specified day. The interviewer then collects the diary at the second visit. The latter visit can also be used to validate some of the respondents' answers (Ampt & Ortuzar, 2011). On the other hand, interviewers only visit respondents once in Austria and Germany. The respondents are handed the trip diary and asked to mail it back upon completion (Ampt & Ortuzar, 2011).

TABLE 2: SURVEY MODE, SAMPLE SIZE AND RESPONSE RATES OVER TIME

Country/Region	Period	Season	Panel	1 day	2 or 3 days	7 days	Long Distance
Nation Wide Surveys							
The Netherlands	1978-onwards	All year	No	X	Before 1985		No
The Netherlands (LVO)	1984-1989	March-Autumn	Yes			X	Yes
Great Britain (NTS)	1988-onwards	All year	No			X	Yes
Denmark	1992-2003 2006-onwards	All year	No	X			1992-2000, 2010
Sweden	1994-2001 2010-2011	All year	No	X			Yes
German Mobility Panel (MOP)	1994-onwards	Autumn	Yes			X	2000-2003
Italy	2000-onwards	All year	No		X		No
New Zealand	2002-onwards	All year	No		X		No
Surveys in Metropolitan Areas							
Seattle: Puget Sound Transportation Panel (PSTP)	1989-2002	Various	Yes		X		No
Montreal	2009-2011	All year	No	X			No
Santiago de Chile Mobility Survey	2001-2002 2004-2007	All year	No	X			No
Melbourne/Victoria (VATS and VISTA)	1994-2002 2007, 2009	All year	No	X			No
Sydney (HTS)	1997-onwards	All year	No	X			No
Perth and Regions Travel Survey (PARTS)	2002-2006	All year	No	X			No
South-East Queensland Travel Surveys	2003-2004 2007-onwards	All year	No	X			No
Nuremberg	1995-onwards	All year	No	X			No
Burgenland and Lower Austria	1998-onwards	All year	No	X			No
Vienna	1998-onwards	All year	No	X			No
Leipzig	1999-2001	All year	No	X			No
Weisbaden	2002-2003	All year	No	X			No
Halle	2000-onwards	All year	No	X			No

TABLE 3: : SURVEY MODE, SAMPLE SIZE AND RESPONSE RATES OVER TIME

Country/Region	Period	Season	Mode	Sample Size (inds/year)	Response Rate
Nation Wide Surveys					
The Netherlands	1978-onwards	All year	RDD	46,000 (1985-1993) 333,000 (1995-1998) 42,000 (2010)	51% (1985) to 35% (1998) 70% (1999-2009)
The Netherlands (LVO)	1984-1989	March-Autumn	N/A	3,500 to 4,000	Low
Great Britain (NTS)	1988-onwards	All year	Face-to-face interviews	10,000 (1989-2001) 30,000 (2002-2008)	80% (1989-1991) 59% (2008)
Denmark	1992-2003 2006-onwards	All year	RDD	25,000 (pre 2002) 20,000 (2002-2003) & (2006-2009) 40,000 (post June 2009)	N/A
Sweden	1994-2001 2010-2011	All year	RDD	11,000 (1995-1998) 8,000 (1999-2001)	70% (1999-2001)
German Mobility Panel (MOP)	1994-onwards	Autumn	N/A	1,600 to 2,000	5 to 10%
Italy	2000-onwards	All year	RDD	15,0000	N/A
New Zealand	2002-onwards	All year	Face-to-face interviews & GPS (2015)	4,400 (2002-07) 9,200 (2008-onwards)	70%
Surveys in Metropolitan Areas					
Seattle: Puget Sound Transportation Panel (PSTP)	1989-2002	Various	Phone-interviews	3,000 to 4,000	N/A
Montreal	2009-2011	All year	RDD (landline plus cell)	30,0000	
Santiago de Chile Mobility Survey	2001-2002 2004-	All year	Face-to-face interviews	30,000 (2002) 10,000 onwards	70% (2002) 45% (2007)

	2007				
Melbourne/Victoria (VATS and VISTA)	1994-2002 2007, 2009	All year	Face-to-face interviews	10,000 to 12,000	60% (1994) 45% (1999) 25% (2002)
Sydney (HTS)	1997-onwards	All year	Face-to-face interviews	10,000	75% (1997) 68% (1999) 63% (2004)
Perth and Regions Travel Survey (PARTS)	2002-2006	All year	Face-to-face interviews	5,000	48% (2003) 49% (2004) 57% (2005) 60% (2006)
South-East Queensland Travel Surveys	2003-2004 2007-onwards	All year	Face-to-face interviews		N/A
Nuremberg	1995-onwards	All year	Drop-off and mail back	14,500 to 19,000	87%
Burgenland and Lower Austria	1998-onwards	All year	Drop-off and mail back	39,000	N/A
Vienna	1998-onwards	All year	Drop-off and mail back	19,000	N/A
Leipzig	1999-2001	All year	Drop-off and mail back	5,300	80%
Weisbaden	2002-2003	All year	Drop-off and mail back	5,000	N/A
Halle	2000-onwards	All year	Drop-off and mail back	10,500 to 15,000	82%

2.1 The Disadvantages of Cross-Sectional Surveys

A cross-sectional survey has several drawbacks when used for household travel surveys. A key issue is that respondents are asked to provide responses for only one weekday, and this collection occurs over a short time period, e.g. September to December. As a result, such data are pooled, and assumed to be representative of a "typical day" of the year. However, the specific time period where the survey is undertaken may be subject to unpredictable events (Stopher & Greaves, 2007). For example, a survey conducted during the 2008 recession would not provide an accurate depiction of regular travel patterns and behaviour. In addition, a cross-sectional survey does not allow for the comparison between short term and long term trends, as data are only collected at a point in time (Kish, 1965).

From the logistical side, the unavoidable loss of experience staff and knowledge during the gaps between cross-sectional surveys is also an alarming issue. It requires new surveyors or third party firms to be contracted each round, who would need to take time to be familiarized with the task and be trained accordingly. Consequently, the rebuilding of a team to conduct such a massive survey, like the TTS, introduces a high ramp-up cost every five years (Ampt & Ortuzar, 2011).

2.2 Advantages of Continuous Surveys

A key aim of a continuous survey is to capture the changing social and economic conditions over time (Ortuzar, et al., 2010). For example, it is expected that a regional travel continuous survey should be capable of depicting the 2008 recession by observing a decline in the number of freight deliveries over that time period. Furthermore, a similar survey should also be able to capture the effect of the current decrease in fuel prices on mode choice. In this way, the global evolution of mobility behaviour over time can be captured.

Due to the sustained data collection effort, a continuous survey exhibits a number of advantages over a one-off large cross-sectional survey. First, a large stream of continuous data can be used to depict travel patterns and behaviour over time, whether it be months, seasons or years. Such depictions can reflect changing social and economic conditions within the study area, such as change in mode choice as a result of fluctuating fuel prices and seasonal effects. It also allows for special surveys, such as panel and process surveys, to be conducted to capture unique travel behaviour (Stopher & Greaves, 2007). In addition, provided that a continuous survey is conducted over the entire week, the average weekend trip rates and travel patterns may also be captured. As it currently stands, the TTS only captures weekday travel behaviour.

Next, in terms of logistic and survey management points of view, it is believed that greater value can be derived from a team that is employed on an on-going basis, as compared to a team that is established for a short period for a cross-sectional survey and then subsequently dismantled. From the budgetary perspective of funding agencies, it may be easier to obtain funds when an on-going survey is established, than for a large one-off cross-sectional survey every five years. That is, the perpetual nature of the survey allows for easier budgeting for municipalities (Stopher & Greaves, 2007).

Finally, from a modelling and statistical investigation perspective, the continuous nature of the data may permit the use of more sophisticated models, such as process models, to investigate dynamics and adaptation of travel behaviour (Ampt & Ortuzar, 2011). Assuming that statistically adequate Origin-Destination (OD) matrices can be generated, the updating of OD matrices for the study area can reflect the differential growth of mobility, filtered by mode and trip purposes. In addition, the short and long term impact of transport policies, and the correlation of changes in transportation demand with changes in supply (i.e. addition of infrastructure, lane closures) may also be assessed with continuous travel data.

2.3 Disadvantages of Continuous Surveys

Theoretically, a continuous survey has several advantages over a cross-sectional survey, but there are some potential pitfalls. Foremost, there is the possibility of insufficient data for conventional travel demand model (trip-based four-stage model) or advanced models (e.g. activity-based models). For instance, the American Community Survey - a general purpose continuous survey conducted in the US to collect data on employment, education, transportation and much more (United States Census Bureau, 2015) - was under heavy scrutiny in 2005 (Stopher & Greaves, 2007). Transportation planners cited serious problems in the survey, such as large standard errors as a result of the small annual sample size limiting the ability of planners to make reasonable conclusions. Another example of unsatisfactory results was the National Travel Survey in Sweden, where a continuous data collection effort was discontinued despite a decent sample of 8,000 individuals per year (Ampt & Ortuzar, 2011). This was due to the fact that transportation planners were unable to detect large changes in travel behaviour, and to follow overall travel developments over time except when examining yearly changes. In fact, most of the changes in travel behaviour were minimal from one year to the next (Ampt

& Ortuzar, 2011). Furthermore, data quality declined over time due to the loss of experienced interviewers and staff. Santiago De Chile faced a similar data quality problem, where some completed surveys were only inputted after 4 months of interviewing respondents (Ortuzar, et al., 2010).

Next, a poorly designed continuous survey may result in household selection bias, where surveyed households become clustered in specific areas (Ampt & Ortuzar, 2011). Ideally, the survey should be evenly spatially distributed, which could prove to be a difficult task when taking into consideration non-response and the temporal nature of the data collection process. Proper weighting and expansion methods should be derived to account for the temporal variation within the data (Ampt & Ortuzar, 2011). In addition, the temporal variability within the data may introduce noise, and as a result, data may also be rendered useless for the first few years of a continuous survey, until sufficient time has passed to collect a statistically significant sample size for various types of models (Ampt & Ortuzar, 2011).

Finally, while reduced cost is often put forth as a positive for continuous surveys, they are not necessarily cheaper than cross-sectional surveys (Peachman & Battellino, 2007). The cost is simply distributed over a longer time period. Efficiency gains can be achieved, however, as processes are streamlined and a definite annual budget is set.

2.4 Panel vs. Repeated Cross-Sectional or Continuous Surveys

Panel surveys differ from continuous or repeated cross-sectional surveys. A panel survey is concerned with gathering information for a predetermined set of individuals or households over a series of time points, or “waves” (Miller, et al., 2012). The same survey is repeated at every time period with the same population subset. This approach has many advantages such as identifying the impact of time related effects, including habit and inertia in transport (Yee & Niemeier, 1996), and allows for a substantial reduction of sample size. On the other hand, repeated cross-sectional data are sampled from the wider population with no replacement. In other words, the same household or individual are not sampled twice. Continuous data do not allow to observe habit formation on the micro scale; however, they do allow for the observation of macro trends within the transport and spatial economy (Yee & Niemeier, 1996).

Unfortunately, panel surveys usually fail to include all segments of the population (different age groups, specific mode shares, etc.), and may lack in proper spatial coverage. Even if an effort is made to develop such a balanced panel, the sample would age/change over time and, thus, would require continuous updating by addition (Ampt & Ortuzar, 2011). Furthermore, respondents may not be willing to keep up with the program as fatigue and other factors, including unexpected life events, occur. This may result in missing data or data attrition (Ampt & Ortuzar, 2011). As a result, the selected sample dataset representation of the wider population can be questioned, due to an increase in bias. One method to reduce bias would be to use sampling weights to adjust trip rates, but the calibration of such weights requires a large cross-sectional dataset. (Ampt & Ortuzar, 2011)

As an illustrative example, a study that compared the statistical robustness between panel and cross-sectional data, using the Puget Sound Transportation Panel dataset, can be referenced (Yee & Niemeier, 1996). The study showed, through an example, that the standard errors of continuous data were large whenever large variations between individuals existed. Therefore, the power to detect statistically significant differences in the estimates could be undermined. On the other hand, using panel data, it was possible to focus on within-subject change and make population inferences accordingly. It can be argued, however, that the objective of a regional household travel survey is to capture macro-level variation, potentially at the zonal level, therefore undermining the importance of individual level differences.

The choice between a panel and continuous dataset is intertwined with the objectives of the stakeholders involved. A repeated cross-sectional dataset is capable of capturing the aggregate effects split by demographic and/or mode. A panel dataset is, instead, more suited to monitor changes in travel activity due to individual attributes. Finally, a continuous survey is more suited to represent the core of the data collection effort, while a panel survey may augment the core of a typical cross-sectional TTS.

3 SAMPLE SIZE, WEIGHTING AND VALIDATION OF DATA

The required sample size to allow for statistically meaningful data from continuous household travel surveys has not received significantly rigorous attention by researchers. There have, however, been a few studies on the determination of sample size, weighting, expansion and data validation techniques for continuous surveys. A summary of these examples are provided in this section.

3.1 Sample Size and Pooling Techniques

The decision on the appropriate sample size for any multi-objective survey is controversial in nature (Stopher & Jones, 2001). For example, the Montreal Regional O-D Continuous Survey divided the sample size of a typical cross-sectional survey over the 4 years of the continuous data collection time frame. This produced a sample size of approximately 1% for each year. On the other hand, the Sydney Household Travel Survey adopts a much smaller sample size of 3,000 households per year, the sum of which over a four-year period represents approximately 1% of the Greater Sydney Area population.

At the heart of the decision of what sample size to use is the generation of statistically adequate origin-destination matrices. This is because the data size requirements for trip generation and mode choice modelling are usually small in comparison to trip distribution (OD) matrices (Smith, 1979). Michael E. Smith (1979) argued that if an interchange is to have a volume of 1000 trips at 90% confidence and a 25% level of accuracy, a 4% sampling rate is required (Smith, 1979). Nonetheless, the above argument falls short for continuous surveys, where OD matrices should be periodically updated. Cools et al. (2010) calculated Mean Absolute Percentage Error (MAPE) of OD matrices for different sampling rates generated using the Belgium national census (Cools, et al., 2010). They concluded that an OD matrix reproduced from a sampling rate of 1% has a MAPE of 19%. However, this is for peak period auto-mode commuter-only travel. On the other hand, Cools et al. (2010) concluded that a general OD matrix for all trip purposes at any time requires an extremely large sample size, almost half of the population, to be statistically adequate. Furthermore, they noted that it may be possible to update the OD matrix each year, thus reducing the 19% error margin. Therefore, depending on the intended use of the OD matrix, a sample size of 1% per year for a continuous survey may be acceptable. A more elaborate discussion on how to update trip matrices is presented in the next section.

Using proper pooling techniques for continuous survey data are also very important to produce a representative sample. Data pooling involves combining more than one source or year of data to form a "pooled" dataset, and estimating econometric models using that dataset (Siikamaki & Layton, 2007). The literature provides one method of pooling techniques within the Australian context. The Sydney household travel survey followed their 1996 cross-sectional survey of 12,000 households with a continuous survey which has since been in place. A relative standard error estimate of each year, as compared to the base year, was calculated to determine the pooling frequency required to simulate the data comparable to a one-off large cross-sectional survey. A 3-year pool seemed appropriate, with a longer period providing minimal reduction in errors (Peachman & Battellino, 2007). This approach provided a happy medium, where a sufficient sample size was available for modelling while accounting for temporal variability. The sample was spread geographically and temporally, capturing all traffic analysis zones across the 4 seasons and the 12 months of the year (Peachman & Battellino, 2007).

Ortuzar (2004) provides another alternative to simply pooling data (Ampt & Ortuzar, 2011). He suggests starting with a bigger survey – e.g. three times the predetermined continuous sample size – for the first year. This overcomes the "cold-start" problem of continuous survey efforts, where no data are available for statistical analysis in the first few years of a study. The Year 2 sample can then be integrated with year 1 using the multi-proportional weighting technique (See Section 3.2).

Data fusion is also an attractive option to increase the sample size and the “richness” of continuous travel survey data. However, the underlying assumption of the transferability of data across space and time needs to be carefully investigated. However, the usefulness and viability of data fusion techniques has to be assessed on a case-by-case basis. (Stopher & Greaves, 2007)

3.2 Weighting

The design weight is the average number of units, be it persons, households or trips, in the surveyed population that each sampled unit represents (Kish, 1965). Traditionally, the weight for the unit is assigned using the inverse of the inclusion probability. The inclusion probability is calculated by dividing the sample size by the true population size, which can be obtained from the census for example. That said, for the case of a continuous survey, it is important to develop a weighting process that takes into account variations over time (Ortuzar & Willumsen, 2011). Ampt and Ortuzar advocate for the use of the multi-proportional method for updating “important variables” such as household size, number of vehicles owned, etc. (Ampt & Ortuzar, 2011). A simple explanation is provided below:

- Select the parameter of interest for weighting – example: household size
- Outline the sample proportions for each household size category (1 to 6 for example) for year 1 and year 2. The proportions should be displayed in absolute numbers and percentages.
- Calculate the weight adjustment factor by dividing year 2 proportion percentage by that of year 1.
- Multiply year 1 absolute proportions by the adjustment factor to get the true sample of the category
- Sum up the samples from year 1 and 2 to represent the up to date sample distribution

This method accounts for variations in year *t* and *t*-1 in how the sample proportions are distributed (mean and variance of each category). Areas of low variance do not need to be weighed in such a manner. If the sample year corresponds with a census year, then traditional weighting against the census can be used. Furthermore, imputation methods can be used to fill in missing values. Examples include using the zonal mean to fill in an empty cell (Ampt & Ortuzar, 2011). No other explicit weighting method in continuous surveys was found.

3.3 Validation

It is very difficult to statistically assess the adequacy of survey results. Making comparisons with a census or other surveys is troublesome as the instruments and techniques used can vary, leading to an increase in bias (Stopher & Jones, 2001). Nonetheless, some validation schemes have been found in the literature.

Using GPS assisted sub-sample data for validation is one such scheme (Stopher, et al., 2007). Through the use of GPS, the entity in charge of surveys can check if the respondents accurately report trip start and end times, trip lengths and distances, and trip origin and destinations accordingly. Nonetheless, a representative sample is needed to provide significant results. In addition, the survey instruments and techniques in use must match those used by the non-GPS survey respondents.

Another method of validation, specifically to check whether the interviewer completed his/her workload, is by randomly dialing/visiting/connecting with the respondents and asking them predetermined questions (Peachman & Battellino, 2007). Such questions include whether they have completed the survey and asking about basic socio-demographic info. This method can be extended to verify trip rates on another 24-hour day assigned to the respondent. In Sydney, for example, 10% of all interviewer completed workloads are validated using this method.

4 REGIONAL CONTINUOUS HOUSEHOLD TRAVEL SURVEY EXAMPLES – THE GREATER SYDNEY AND MONTREAL AREAS

4.1 Summary of the Sydney Household Travel Survey

Sydney has one of the oldest continuous household surveys. The Sydney Household Travel Survey (HTS) was initiated in 1997 with an annual sample size of 5,000 households, equivalent to 1% of Sydney's population, over a 4 to 5 year period (Peachman & Battellino, 2007). The data are used to generate transport trends in the Sydney Greater Metropolitan Area (GMA), undertake detailed analysis of areas or transport corridors, and to provide input to the Sydney Strategic Travel Model (STM) (Bureau of Transport Statistics, 2013). Prior to the continuous survey, Sydney instead conducted a large cross-sectional survey every 10 years. The region decided to switch to a continuous survey with the objective of collecting more timely data to meet their transportation needs (Ampt & Ortuzar, 2011). Each survey period starts on a Sunday in the Month of June and ends on a Saturday in June of the following year (Bureau of Transport Statistics, 2013).

The GMA (also known as the GSMR or the Greater Sydney Metropolitan Area) consists of Statistical Subdivisions (SD), Statistical Subdivisions (SSD), and 80 Statistical Local areas (SLAs). The SDs and SSDs are the equivalent of a Census Division and a Census Subdivision in the GTA. An SLA however is a bit larger than a typical GTA Dissemination Area.

4.1.1 Survey Mode and Method

A multi-stage stratified sampling technique has been adopted for data collection. This involves first randomly selecting Travel Zones (TZs) within SLAs. A random dwelling is then selected within a random block in that TZ for surveying. The sample is spread spatially and temporally to cover all geographic areas and days of the year. However, all surveys are conducted face to face, with an invitation by mail sent two weeks prior to the interview. All household residents are interviewed, with each member asked to recall travel activity over a 24-hour period. (Bureau of Transport Statistics, 2013)

4.1.2 Sample Size and Pooling Technique

The sample size for the continuous survey was estimated by calculating relative standard errors (RSEs). Using the cross-section survey of 1991 as a base year, Sydney estimated the RSEs comparing aggregated or averaged values of yearly waves with the 1996 base survey (Figure 1).

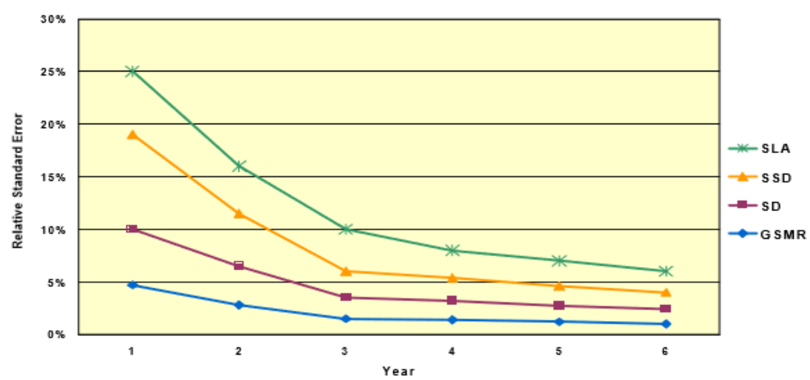

Figure 1 - Relative Standard Errors for trip estimates at varying spatial units[1]

[1] Figure copied from (Peachman & Battellino, 2007)

The metropolitan agency concluded that the variation at the SLA becomes minimal after 3 years, with the exception of some SLAs. Therefore, the agency decided to use a method of optimal allocation, potentially over-sampling SLAs with a large variation versus SLAs with a much smaller reported RSE. From this, the conclusion was to use a sample of between 3,000 to 5,000 households annually. The maximum acceptable threshold for an SLA's RSE was identified at 10%. (Bureau of Transport Statistics, 2013)

4.1.3 Weighting and Expansion

For weighting and expansion, Sydney uses both pooled and annual approaches. The pooled approach involves pooling three years of survey data to produce one dataset, which is then weighted and expanded to represent the wider population. On the other hand, for the single year approach, estimates are weighted for a one-year period of the HTS. Weighting is conducted on three levels: Household, Individual and Region Day Factors. For household, the inverse of the probability of selection is used for weighting. Household population benchmarks are required for post-stratification weighting and expansion, and are usually obtained from the most up to date census. Weighting adjustments are then executed at the SLA level to provide an adequate representation of household types across all 80 SLAs. The same approach is followed for person weighting. The main variables of interest are age and sex. As for the final level (region day), every day of the week is considered as a sub sample. The aim is to have equal representation of sample sizes and proportions, and so exact day factors are computed accordingly and applied only at the region level. (Peachman & Battellino, 2007)

4.2 Summary of the Montreal Experience

An experimental continuous origin-destination survey was conducted by the Agence Métropolitaine de Transport (AMT) in Montreal. The survey started in January 2009 and ended in December 2012. The over-arching goal was to add value to the regional Montreal cross-sectional 4-year surveys, conducted in 2008 and 2013 (Tremblay, 2014). Approximately 15,000 households were surveyed per year. The sample size was determined by splitting the typical 4% to 5% cross-sectional survey over a 5-year period. In other words, the total sample surveyed was about 63,000 households, which is equivalent to the total number of households surveyed in a 5-year transportation plan. The survey was conducted in a similar fashion to that of Sydney; i.e. in three waves every year.

The continuous survey had three main objectives, quoting from a presentation by Pierre Tremblay's, head of the transportation systems modelling unit at the Ministry of Transportation in Quebec (Tremblay, 2014):

- Develop annual and seasonal mobility pictures
- Produce high level indicators to monitor progress towards policies and transportation plans targets (e.g. annual reports)
- Maintain technical & organizational knowledge / staff experience between [the two] 5 years large scale surveys

The Montreal continuous survey details mentioned below can all be found in Pierre Tremblay's presentation (Tremblay, 2014).

4.2.1 Sampling Frame, Survey Modes and Instruments

The sampling base of the continuous Montreal survey was a hybrid of cell phone, land-line and web-based survey tools. The 2008 questionnaire was unadjusted for the continuous survey except for the addition of some new questions on disability mobility, auto availability and respondent arrival time. The addition of the 3 questions cost nearly one additional minute on average interview time. The final results were expanded based on the 2011 census.

The planning agency, in an attempt to capture households with no landlines integrated a cell phone based sample. Both a validated cell phone list and random digit dialing was used. The validated list came with a cost of $4/person, while random digit dialing only cost 4 cents/person. However, the productivity and completion rate of the validated list was approximately 23 times that of the randomly dialed list, and most randomly dialed individuals had a landline. The cell-based sample proved to be quite young with most individuals lying in the lower income, no car, and no-kids demographic with a preference for active and/or transit mobility.

A postal address sampling frame was also used. The addresses in the list were validated against the current list of landline-based households. Households that happened to be on both lists were taken out. The remaining survey population was asked to fill the survey using the Polytechnique's WebSurvey tool. A completion rate of only 7% was achieved (135 households). No apparent differences in socio-demographics and travel behaviour were noted between the landline based and postal based sampling frames.

4.2.2 Data Collection, Staff Management and Continuous Reporting

It is a complex task to select personnel, train them and keep them all motivated throughout the survey process (Ampt & Ortuzar, 2011). During the execution years of the Montreal continuous survey, it took the call centre 2 months to reach a completion rate of 3 interviews/hour, including some time spent to fine tune the utilized software tools. The firm in charge conducted continuous training activities to keep the interviewers up to the task. Furthermore, staff turnover was minimized by introducing incentives and rewards on a regular basis. Examples of incentives and motivation strategies included: keeping interviewers aware of their performance metrics and quality indicators, initiating a $50 monthly draw prize for the best performing interviewers, and giving the best interviewers the opportunity to be part of the survey design team.[2]

After collecting the data, basic respondents' details were immediately verified, and their respective addresses were geocoded automatically. Invalid interviews were also immediately rejected, while missing values were imputed on the go. Aggregated results were reported on a yearly basis.

4.2.3 Status of Current Results

To date, AMT has found it difficult to fit the existing results with the 5 year trends (Tremblay, 2014). In addition, the fall sample has been reported to be too thin to measure significant annual variations at the sub-district level. Thus, seasonal trends were subsequently difficult to capture. The 2013 cross-sectional survey will assist in the validation of the continuous survey results as the surveying team will be able to verify whether the trends captured through the continuous survey fit the 2013 large cross-sectional survey. Other problems, as previously touched on, include the specification of the sampling frame and the staff management.

[2] The information regarding on the job interviewer incentives were relayed by a colleague who interviewed one of the team members of the Montreal continuous survey team.

5 MODEL DEVELOPMENT USING CONTINUOUS SURVEY DATA

For a continuous survey to act as a suitable substitute for the traditional TTS cross-sectional dataset, regional stakeholders must be capable of using the data to build and calibrate a four stage transportation model.

5.1 Mixed Effects Model for Trip Generation

Trip generation is defined as the total number of trips generated by a household (or a person). The trip may originate from or end at a household (Ortuzar & Willumsen, 2011). The two main forms of trip generation in use today are linear regression and cross classification tables. Linear regression is a statistical process estimating the relationship between variables, for example, between trip generation from a household and a set of personnel, household and/or zonal attributes. Cross Classification tables are similar to regression in the sense that trip generation is captured, but the number of variables or categories factored is limited (usually only two). The method, however, has two main drawbacks. The sample size required for generating cross class tables is typically large, and it assumes that trip generation rates are stable over time (Ortuzar & Willumsen, 2011). As the main objective of a continuous survey is to capture temporal trends in trip behavior, the remainder of this section will focus on regression analysis for trip generation.

It may be inadequate to build trip generation models on continuous datasets using simple linear regression due to the time series nature of data. In a continuous dataset, the events or trips happening in zone i at time j = 1 are likely to be correlated with trips occurring in zone i at time j = 2. This violates the independence assumption of linear regression (Ortuzar & Willumsen, 2011).

A more adequate alternative approach is a mixed effects/multilevel framework (DiPrete & Grusky, 1990). A multilevel model, in simple terms, may be perceived as a traditional regression model that relaxes the assumption of independence of observations. It may be conceptualized as a hierarchy of a system of equations, where the individual or household level variation within each sample is explained with a micro-equation, while capturing the cross group variation of, for example, zones or years (DiPrete & Grusky, 1990). In other words, in the case of a continuous survey, individuals maybe nested within their respective households, households in zones, and zones in years, where the variation within and across each level maybe explained. Plus, using multilevel regression allows the modeller to correlate the temporal residuals of j =1 and j = 2, j=2 and j = 3, and so forth, where j may be defined as a specific time point. Furthermore, a multilevel/mixed effects model can capture the heteroscedasticity of data, the variance contribution of various levels using a nested hierarchy, and the intra-class correlation of within level residuals. Ignoring the intra-class correlation may lead to inflated type I errors and biased standards of deviation (Rabe-Hesketh & Skrondal, 2012).

A few examples of this approach may be found in the literature. This includes Goulias's work in modelling the individual choices of time allocation to maintenance, subsistence, leisure, and travel time. He used a panel dataset, and developed a nested data hierarchy of households, persons, and occasions of measurement (Goulias, 2002). Another study was conducted by Lipps and Kunert (2005) using the National Travel Survey dataset in Germany. The study attempted to capture and predict trip travel distances using socio-demographic data and spatial characteristics. The nature of the dataset was repeated cross-sectional with participants surveyed over 4 waves from 1976 to 2002. All four waves covered seasonal and spatial variation over a 12 month period (Lipps & Kunert, 2005).

For a continuous TTS, a mixed effects modelling structure is recommended to predict trip rates using continuous data while correlating successive time periods. The fixed effects for the variables under study (household size, number of vehicles, income, etc.) can be produced while accounting for the random effects per spatial unit (i.e. zone) or time period (i.e. year). A unique slope and/or intercept may be generated for variables of interest for each time period and/or each spatial unit. Such a modelling framework can not only identify the development of trends over time, but can also identify the variables that have the greatest effect on these trends. Other examples of time series modelling frameworks are simply less dynamic in comparison with multilevel models, such as growth or distributed lag models (Steele, 2011).

5.2 Origin – Destination (OD) Matrices Using Continuous Data

The construction of statistically adequate Origin-Destination matrices lies at the heart of large household travel surveys' sample size estimation. Consequently, the ability to reproduce O-D matrices using continuous data with a reduced annual sample size is imperative for the consideration of a potential transition to a continuous survey approach. However, no published research has been found to provide a practical solution or approach to this exact issue. Given that, continuous or not, most household travel surveys outside Canada exhibit a relatively small sample size (usually less than 1%), transportation agencies have adopted other means to generate OD matrices, such as simulation or the use of data from highway loop detectors (Ampt & Ortuzar, 2011). That said, a smaller sample size of 1%, such as that of the Montreal continuous survey (1%/year) can still produce a statistically adequate OD matrix with an absolute mean percentage error of approximately 19% for peak period auto commuters (Cools, et al., 2010). It is important to note, however, that the error margins for the other trip purposes, modes and during non-peak periods will generally be higher than just 19%.

One idea, similar to the current TTS, is to simply produce O-D matrices from the fall period of yearly continuous data. To resolve the issue of small sample size, the O-D matrices over a five-year period can be combined and updated. For example, the regional O-D matrix of each year can be compared to the highway traffic counts to calculate the mean absolute percentage error (MAPE). A confidence factor can then be assigned to each O-D matrix, where the sum of all values equals to 1. Next, the matrices can be combined to generate a statistically adequate five-year matrix, similar to that of the cross-sectional TTS. Appendix 1 provides an illustration of how to construct this matrix.

5.3 Estimating Mode Choice Models Using Repeated Cross-Sectional Data

A significant proportion of travel behaviour research is centred on the estimation of discrete choice models. To be considered as a viable substitute, continuous or repeated cross-sectional data must lend itself for the formulation of mode choice and trip behaviour models.

Recently, Habib et al. used TTS data from 1996, 2001, and 2006 to test the viability and robustness of using repeated cross-sectional data for estimating mode choice models (Habib, et al., 2014). The authors proposed a non-linear (polynomial or logarithmic) function of time to capture the evolution of consumer preferences. A pooled data model specification was suggested. The model captured the error structure and the scale parameter of an entropy based heteroscedastic Tree Extreme Value (hTEV) model over time. Such a specification was stated to capture the temporal evolution of mode preferences. The proposed model considered 1996 as the base year. The authors concluded that the pooled model outperformed year-specific models (currently in use in Toronto) in terms of model transferability. The pooled model may also be more robust for long-term forecasting (Habib, et al., 2014).

An example of using repeated cross-sectional data for activity generation may also be found in literature. The paper authored by Salem and Habib (2015) pooled 3 waves of TTS data to develop a meta-model of activity generation processes. The authors concluded that the use of multiple repeated cross-sectional data improved temporal transferability of the model significantly (Salem & Habib, 2015).

The Bureau of statistics and Analytics in Sydney Australia also uses daily repeated cross-sectional data for region wide mode choice estimation and long term forecasting. Continuous data are pooled to ensure a sufficient sample statistically for modelling purposes. The demand models are updated every five years, in line with the census (Bureau of Transport Statistics, 2013).

It is important to note that for the implementation of the methods above, some form of aggregation or data subsetting must be performed. That is, the fall periods of every year may be separated from the continuous data for a repeated cross-sectional modelling implementation. This is nothing new to the TTS as the five-year repeated cross-sectional survey is conducted over the entire fall period. The data are then aggregated to get the average trip behaviour of a "typical weekday" (Data Management Group, 2013).

5.4 Comparing Continuous and Cross-sectional Data on Mode-Destination Choice Models Temporal Transferability

An investigation targeting the temporal transferability of mode-destination choice models was undertaken by researchers from the University of Leeds, with the assistance of Professor Eric Miller. Temporal transferability of a model refers to the applicability of a model developed using data at one point in time at another point in time (Fox, et al., 2014). They used historical TTS data which, while cross-sectional in nature, may be perceived as continuous data with a wave surveyed every 5 years. The researchers concluded that the long-term transferability of the models is at question as some key variables, such as cost and trip rates, are either over or under estimated (Fox, et al., 2014). Nevertheless, for a more related comparison, the researchers compared the model temporal transferability when using classical continuous data from Sydney, Australia. The nature of the data, whether continuous or cross-sectional, did not significantly improve or deteriorate the temporal transferability of the mode-destination choice model. It is important to mention, however, that the continuous data from the Sydney Household Travel Survey was aggregated by year (Fox, et al., 2015).

6 LEVERAGING NEW SURVEY MODES FOR A CONTINUOUS SURVEY

The majority of continuous surveys, as shown by Table 3, rely on either landlines or face-to-face interviews to survey respondents. However, the use of a landline based sampling frame can result in an under-representation of certain demographics, primarily the 18-35 age group, as seen in the 2011 TTS (Data Management Group, 2011). Web-based surveys and passive modes, such as the use of smartphone apps and GPS, due to their reduced respondent burden exhibit significant potential for continuous data collection.

A web-based survey is known to have quite a few benefits. It requires less personnel as compared to that of a landline to manage the data collection process; this can lower the operational cost. Furthermore, the respondents can fill the survey at a time and pace of their choice; however, the personnel in charge of the survey will still have to make frequent calls for a subset of the surveyed sample population for validation purposes. This is in line with the most recent TTS, where respondents were provided with the option of completing the survey using a web-tool (Data Management Group, 2013). Thus, it is recommended that a web-tool along-side a hybrid cell and landline directory be used to shape the core of a potential continuous survey.

Next, passive or pseudo-passive data collection techniques, such as smartphone apps and GPS, are also a promising mode for continuous data collection. Data can be collected for a particular respondent over a longer period of time (e.g. a week). This can significantly reduce the sample size requirement (Stopher, et al., 2008). It is also likely that a mobile app will be more likely to capture the aforementioned under-represented demographic group. However, some issues such as signal loss and cost for GPS, and battery life and sample representativeness for smartphone apps, still have to be resolved before a large scale implementation of such modes is viable (Houston, et al., 2014). Therefore, the recommendation is to conduct a panel satellite surveys using GPS/smartphone technology, which can then be an augment to the core survey.

7 RECOMMENDATIONS FOR PILOT TESTING

1. Analysis of the Montreal continuous survey experiment

One of the main objectives of continuous surveys is to capture the temporal and spatial development of trip rates and travel behaviour. The use of simple linear regression models falls short for complex time series analysis, potentially needed to investigate trip behaviour using continuous data. A pilot is recommended to investigate the use of more complex modelling approaches, such as auto-regressive mixed effects models. The flexible nature of the models can be used to capture temporal variations in trip behaviour in Montreal. Mixed effects models are capable of capturing the within and between class variances. Further, clustering effects can be accounted for. For example, households in zone A tend to be more similar in their trip behaviour than households in zone C, etc. Random intercepts and slopes can be generated for each year/season/month and potentially week to capture travel behaviour development over time. A first order auto-regressive (i.e. trip rates in Year 2 and correlated with trip rates in Year 1) relationship between sequential years can be assumed.

2. Analysis of the 2011/2012 TTS as a pseudo-continuous survey

The 2011/2012 TTS was conducted over a two-year time period. The respondents were surveyed from September to December in each of the two years. In other words, the 2011/2012 TTS can act as a repeated cross-sectional survey consistent of two waves. The data can potentially be used to investigate trip behaviour trends over time. Month by month OD matrices can be generated. Pooling and OD matrices updating techniques can be investigated. The mean absolute percentage error of the updated OD matrix can be cross-checked with the previously generated matrix currently in use for modelling purposes by TMG.

3. Determining sample size and pooling method for a continuous survey

The Montreal dataset may be used to determine the optimal sample size needed for a continuous survey. The 2008 cross-sectional survey can be used as a base. Similar to the Sydney HTS, the residual standard errors (RSEs) of each yearly wave on different spatial scales can then be calculated. The RSEs results may then be plotted. The results of this pilot will help identify a satisfactory pooling mechanism for a continuous survey. Furthermore, the construction of various OD matrices using different sampling rates could be investigated to identify an appropriate sample size.

4. Investigation into use of web and smartphone survey methods for continuous surveys

Most continuous surveys have been or are being conducted through the use face-to-face interviews or using a landline directory. Very few surveys have adopted web or passive technologies for data collection. These tools provide for promising avenues for continuous uninterrupted data collection over a potentially extended period of time. A satellite survey using one or both of the above mentioned tools can act as a great pilot test for data validation. The use of a commercial app is recommended to reduce cost and avoid extensive development time.

8 BIBLIOGRAPHY

Ampt, E. & Ortuzar, J., 2011. On Best Practice in Continuous Large-Scale Mobility Surveys. *Transportation Reviews,* 24(3), pp. 337-363.

Bureau of Transport Statistics, 2013. *Household Travel Survey 2011/12,* Sydney, Australia: s.n.

Cools, M., Moons, E. & Wets, G., 2010. Assessing the Quality of Origin–Destination Matrices Derived from Activity Travel Surveys: Results From a Monte Carlo Experiment. *Transportation Research Record: Journal of the Transportation Research Board,* Issue 2183, pp. 49-59.

Data Management Group, 2011. *Transportation Tomorrow Survey,* Toronto: Transportation Information Steering Committe.

Data Management Group, 2013. *Transportation Tomorrow Survey.* [Online]
Available at: http://www.dmg.utoronto.ca/transportationtomorrowsurvey/
[Accessed 2015].

DiPrete, T. & Grusky, D., 1990. The Multilevel Analysis of Trends with Repeated Cross-Sectional Data. *American Sociological Association,* Volume 20, pp. 337-368.

Fox, J., Daly, A., Hess, S. & Miller, E., 2014. Temporal Transferability of Models of Mode-Destination Choice for The Greater Toronto Area. *The Journal of Transport and Land Use, 7*(2), pp. 41-62.

Fox, J., Hess, S. & Daly, A., 2015. *Temporal Transferability of Models of Mode and Destination Choice.* Windsor, s.n.

Goulias, K., 2002. Multilevel Analysis of Daily Time Use and Time Allocation to Activity Types Accounting For Complex Covariance Structures Using Correlated Random Effects. *Transportation,* Volume 29, pp. 31-48.

Habib, K., Swait, J. & Salem, S., 2014. Using Repeated Cross-Sectional Travel Surveys to Enhance Forecasting Robustness: Accounting for Changing Mode Preferences. *Transportation Research Part A,* Volume 67, pp. 110-126.

Houston, D., Luong, T. & Boarnet, M., 2014. Tracking Daily Travel: Assessing Discrepancies Between GPS-Derived and Self-Reported Travel Patterns. *Transportation Research Part C: Emerging Technologies,* Volume 48, pp. 97-108.

Kish, L., 1965. *Survey Sampling.* New York: John Wiley & Sons Inc..

Lipps, O. & Kunert, U., 2005. Measuring and Explaining The Increase in Travel Distance: A Multilevel Analysis Using Repeated Cross-Sectional Travel Surveys. *DIW-Diskussionspapiere,* Volume 492.

Miller, M. et al., 2012. *Changing Practices in Data Collection on the Movement of People,* Quebec: Lee-Gosselin Associates Limited.

National Institute of Statistics and Economic Studies, 2004. *Census Survey.* [Online]
Available at: http://www.insee.fr/en/methodes/default.asp?page=definitions/enquete-de-recensement.htm
[Accessed 2015].

Ortuzar, J., Armoogum, J., Madre, J. & Potier, F., 2010. *Continuous Mobility Surveys: The State of Practice,* s.l.: Transport Reviews.

Ortuzar, J. & Willumsen, L., 2011. *Modelling Transport.* 4th ed. s.l.:Wiley.

Peachman, J. & Battellino, H., 2007. The Joys and Tribulations of A Continuous Survey. *International Conference On Transportation Survey Quality and Innovation.*

Rabe-Hesketh, S. & Skrondal, A., 2012. *Multilevel and Longitudinal Modelling Using Stata.* Texas: Stata Press.

Salem, S. & Habib, K., 2015. Use of Repeated Cross-Sectional Travel Surveys To Develop a Meta Model of Activity-Travel Generation Process Models: Accounting for Changing Preferences in Time Expenditure Choices. *Transportmetrica A: Transportation Science,* 8(11), pp. 729-749.

Siikamaki, J. & Layton, D., 2007. Discrete choice survey experiments: A comparison using flexible methods. *Journal of Environmental Economics and Management,* 53(1), pp. 122-139.

Smith, M., 1979. Design of Small-Sample Home-Interview Travel Surveys. *Transportation Research Record: Journal of the Transportation Research Board,* Issue 701, pp. 29-35.

Stopher, P., FitzGerald, C. & Xu, M., 2007. Assessing the Accuracy of The Sydney Household Travel Survey With GPS. *Transportation,* Volume 34, pp. 723-741.

Stopher, P. & Greaves, S., 2007. Household Travel Surveys: Where Are We Going?. *Transportation Research Part A,* Volume 41, pp. 367-381.

Stopher, P. & Jones, M., 2001. *Developing Standards of Transport Survey Quality,* South Africa: International Conference on Transport Survey Quality and Innovation: How to Recognize It and How to Achieve It..

Stopher, P., Kockelman, K., Greaves, S. & Clifford, E., 2008. Reducing Burden and Sample Sizes in Multiday Household Travel Surveys. *Transportation Research Record: Journal of the Transportation Research Board,* Issue 2064, pp. 12-18.

Tremblay, P., 2014. *An overview of OD-Surveys in Quebec.* [Online]
Available at: http://uttri.utoronto.ca/files/2014/10/5-Tremblay-An-Overview-of-OD-Surveys-in-Quebec.pdf
[Accessed 2015].

United States Census Bureau, 2015. *American Community Survey.* [Online]
Available at: https://www.census.gov/programs-surveys/acs/about.html
[Accessed 2015].

Yee, J. & Niemeier, D., 1996. *Advantages and Disadvantages: Longitudinal vs. Repeated Cross-Section Surveys,* California, USA.: Federal Highway Authority.

9 APPENDIX A: ANNOTATED BIBLIOGRAPHY

Title	**Continuous Mobility Surveys: The State of Practice**
Author(s)	Ortúzar, J. D. D., Armoogum, J., Madre, J. L., & Potier, F.
Citation	Ortúzar, J. D. D., Armoogum, J., Madre, J. L., & Potier, F. (2011). Continuous mobility surveys: the state of practice. *Transport Reviews*, *31*(3), 293-312.
Summary	The paper provides a comprehensive literature review on the practice of continuous surveys. The advantages and disadvantages of both continuous surveys and cross-sectional surveys are provided. A summary list of the continuous surveys in practice is also provided at the end of the paper.
Potential Applications	• Develop a general understanding of continuous surveys, the state of the practice, and its advantages and disadvantages in relation to one-off cross sectional surveys
Strengths	• Provides examples from the state of the practice • Outlines the different forms of continuous surveys along with their advantages and disadvantages
Weaknesses	• Does not provide a practical example on how to conduct and analyze a continuous survey using statistical inference • Very broad approach to the topic

Title	**Household Travel Surveys: Where Are We Going?**
Author(s)	Stopher, P. R., & Greaves, S. P.
Citation	Stopher, P. R., & Greaves, S. P. (2007). *Household travel surveys: Where are we going?* Transportation Research Part A: Policy and Practice, 41(5), 367-381.
Summary	After discussing the current trends in survey implementation in North America, the Author describes the emerging trends in survey design that may (or may not) replace the traditional diary. Trends include: GPS technology, panel surveys, and continuous surveys. The author also touches on the potential of data fusion techniques in simulating transportation behaviour for modelling purposes. It also describes the demands placed on data, especially for the estimation of demand models.
Potential Applications	• To develop an understanding of current practices from an ad-hoc perspective
Strengths	• Provides a more in depth analysis of some of the large continuous surveys around the world • Provides a recommendation on how to conduct a state of the art continuous survey
Weaknesses	• Doesn’t provide an empirical exercise for pooling, weighing, updating or modelling data • Does not provide statistical evidence for sample size • Does not discuss how to generate OD Matrices from continuous data

Title	**On best practice in continuous large-scale mobility surveys**
Author(s)	Ampt, E.S. and J. de D. Ortúzar.
Citation	Ampt, E.S. and J. de D. Ortúzar. (2004). On best practice in continuous large-scale mobility surveys. *Transport Reviews* 24, 337-363.
Summary	The author discusses the best practice in designing a large scale Continuous mobility survey using the most up to date practices and techniques. He commences by stressing the need to identify the objective that the survey intends to fulfill. He lists the points below to summarize the elements in need of consideration upon survey design. The results of a one year continuous study from Santiago are also displayed. Mechanisms on sample size estimation alongside weighing techniques are presented. The paper suggests that a relatively large "entry" survey should first be designed, followed by a series of smaller surveys for updating purposes.
Potential Applications	• The methodologies explained provide insight that can be used to develop a pilot continuous survey
Strengths	• Provides an optimization strategy to estimate sample size by category and by zone • Provides a weighting mechanism to update the continuous survey
Weaknesses	• Santiago specific • Survey needs to be objective oriented (well defined) • Does not explain how to split the aggregate one of cross-sectional survey into disaggregate chunks or samples to be surveyed each year

Title	**The Joys and Tribulations of a Continuous Survey**
Author(s)	Battellino, H., & Peachman, J.
Citation	Battellino, H., & Peachman, J. (2003). The joys and tribulations of a continuous survey. *Transport survey quality and innovation*, 49-68.
Summary	This paper handles the Sydney continuous Household Travel Survey (HTS), initiated in 1997, in great detail. The survey is conducted face to face, and respondents are asked to recall trips over a full 24 hour period. The survey is conducted in the Greater Sydney Metropolitan Region, area of approximately 25,000 square kilometres with a population of 4.9 million. The authors state that in the last cross-sectional survey (1991), a sample of 12,000 households was carried out – equivalent to 1% of the total population. The strategy of the continuous survey is to replicate this sample size over a 3 year period, which adds to approximately 3,500 households per year. Nonetheless, the gross number of households surveyed each year was calculated to be about 5,000 to produce statistically significant models.
Potential Applications	• Provides another example on how to implement a continuous travel survey
Strengths	• A brief mentioning of weighting techniques is provided • Relative standard error, compared to the base case of 1992 was calculated • Details of designing and conducting the survey where discussed
Weaknesses	• No statistical illustration, aside from the RSE calculation was provided to show the adequacy of the method in comparison with the one-off travel survey

Title	**Assessing the Accuracy of The Sydney Household Travel Survey with GPS**
Author(s)	Stopher, P., FitzGerald, C., & Xu, M
Citation	Stopher, P., FitzGerald, C., & Xu, M. (2007). Assessing the accuracy of the Sydney Household Travel Survey with GPS. *Transportation*, *34*(6), 723-741.
Summary	A small sample of about 50 household was recruited. The sample was given GPS devices and their trip behaviour was observed for a 24 hr period. The objective of the survey was to compare the results of the GPS diary with the self-diaries completed via interview in Sydney. The study concluded that the continuous travel survey under reports trips and trip attributes by about 7%, which is less than the CATI approach error of 20 to 30% for cross-sectional surveys.
Potential Applications	• Measuring trip and trip attributes error using GPS devices. The study provides one way of validating trip data.
Strengths	• Demonstrates potential of using GPS alongside travel surveys for measuring the accuracy of reporting trip related information.
Weaknesses	• Bias of survey instrumentation and techniques used is not accounted for. Thus, it is difficult to conclude much from this survey. • The GPS sample size is so small.

Title	**The Multilevel Analysis of Trends with Repeated Cross-Sectional Data**
Author(s)	DiPrete, T. A., & Grusky, D. B.
Citation	DiPrete, T. A., & Grusky, D. B. (1990). The multilevel analysis of trends with repeated cross-sectional data. *Sociological Methodology*. Vol. 20. pp. 337-368.
Summary	A first order auto-regressive multi-level model is suggested for the analysis of trends using longitudinal data. Using such a model, the subjects of interest may be nested to account for clustering. Parameters' random and fixed effects coefficients can be estimated to account for varying slopes and intercepts. The first-order autoregressive nature of the models allows for the correlation of residual errors of the highest order nest, thus accounting for temporal relationship of events over time.
Potential Applications	• The model suggested can be used to depict trends over time using continuous cross-sectional surveys while accounting for the temporal relationship of the events
Strengths	• Within and between class variances ca be calculated to determine the relative source of temporal variation • Intra-class correlation can also be determined • Solves the issue of serial correlation of time series data points
Weaknesses	• The example in the paper was not transportation related. • The procedure on how to implement the model using traditional software was not illustrated

Title	**Advantages and disadvantages: longitudinal vs repeated cross-section surveys**
Author(s)	Yee, J. L., & Niemeier, D.
Citation	Yee, J. L., & Niemeier, D. (1996). Advantages and disadvantages: Longitudinal vs. repeated cross-section surveys. *Project Battelle*, *94*, 16.
Summary	This paper compares the use of longitudinal/panel data vs repeated cross-sectional data for the purpose of constructing a transportation survey. The Puget Sound Transportation Panel data are used as a case study. The discussion paper focuses on the scope and limits of statistical inference for the two type of data sets.
Potential Applications	• Develop a deeper understanding of the differences in statistical power between panel and cross-sectional data sets
Strengths	• Outlines some of the differences between panel and cross-sectional datasets in a statistical manner • Provide an idea of what is the most optimal core design for a regional transportation survey
Weaknesses	• Does not discuss OD matrices • The instruments of data collection were not thoroughly outlined

Title	**Temporal transferability of models of mode-destination choice for the Greater Toronto and Hamilton Area**
Author(s)	Fox, J., Daly, A., Hess, S., & Miller, E.
Citation	Fox, J., Daly, A., Hess, S., & Miller, E. (2014). Temporal transferability of models of mode-destination choice for the Greater Toronto and Hamilton Area. *Journal of Transport and Land Use*, *7*(2), 41-62.
Summary	This paper investigates the transferability of model parameters over time of region wide mode-destination choice models. The research uses historical TTS data represented in the form of cross-sectional surveys. A literature review on the topic is first introduced. Next, the transferability of long term and short term forecasting was examined. Different mode-destination choice models' specifications were tested to account for the impact of specification improvement. The paper concludes that, while mode-destination models captures short term travel trends at a satisfactory level of accuracy, the models either over or under estimate some key parameters sensitive to the development of long term planning policies. Another version of the paper (unavailable) compares the transferability of the mode-destination choice models using TTS data versus continuous/repeated cross-sectional data from Sydney, Australia. The authors conclude that the transferability of the models does not improve or deteriorate with the use of either datasets.
Potential Applications	• Understand the effect of using continuous versus cross-sectional data on the temporal transferability of mode-destination choice models
Strengths	• Concludes that the temporal transferability is unimproved by switching from cross-sectional to continuous
Weaknesses	• The process as to how the data were aggregated and fed into the model is not clearly discussed or illustrated

Title	**Multilevel analysis of daily time use and time allocation to activity types accounting for complex covariance structures using correlated random effects**
Author(s)	Goulias, K. G.
Citation	Goulias, K. G. (2002). Multilevel analysis of daily time use and time allocation to activity types accounting for complex covariance structures using correlated random effects. *Transportation*, *29*(1), 31-48.
Summary	In this study, a multivariate multilevel regression analysis is used to capture travel behaviour over time. The dataset used is the Puget Sound Transportation Panel, conducted in the Puget region of Washington, USA. The author used a nested hierarchy of individuals, households and occasions of study (time) with random effects introduced at each level. The modelling framework assisted the author in identifying the variance contribution of each level, along with the heteroskedasticity within and across. The time variable was correlated. The individual choices of time allocation to maintenance, subsistence, leisure, and travel time were used as an illustrative example.
Potential Applications	• Potential illustration of how to generate trip aggregation models using continuous/longitudinal data
Strengths	• Uses a transportation dataset to illustrate the power of multilevel modelling and its alignment with continuous data • Provides an example of investigating variance contribution and intra-class correlation of nested levels of data for a continuous survey • The above two strengths maybe considered a step forward in identifying a meaningful methodology to extract the temporal variability of travel behaviour from continuous data
Weaknesses	• The nature of the dataset used is longitudinal rather than repeated cross-sectional • Does not touch on the topic of OD matrices • Does not discuss modes of data collection

Title	**Measuring and explaining the increase of travel distance: A multi-level analysis using repeated cross sectional travel surveys**
Author(s)	Kunert, U., & Lipps, O.
Citation	Kunert, U., & Lipps, O. (2005). Measuring and explaining the increase of travel distance: A multi-level analysis using repeated cross sectional travel surveys.*Berlin: DIW*.
Summary	A discussion paper that uses data from the National Travel Survey in Germany. The data are repeated cross-sectional in nature and was collected in four waves since the 1970s. The authors model the relationship between trip distance (dependent variable) and a number of socio-demographic variables for the survey respondents. A multilevel model is used with a nested hierarchy of individuals within households within spatial settings (i.e. zones). The authors also attempt to control for the bias introduced by using different survey methods and sampling schemes at each wave of data collection.
Potential Applications	• Another illustration of how aggregate statistical analysis may be performed using repeated cross-sectional data
Strengths	• Provides a method to account for survey and sampling technique bias • Describes an approach to regress repeated cross-sectional data
Weaknesses	• The dataset is spread over 30 years • The dataset is quite small compared to a TTS

Title	**Using repeated cross-sectional travel surveys to enhance forecasting robustness: Accounting for changing mode preferences**
Author(s)	Habib, K. M. N., Swait, J., & Salem, S.
Citation	Habib, K. M. N., Swait, J., & Salem, S. (2014). Using repeated cross-sectional travel surveys to enhance forecasting robustness: Accounting for changing mode preferences. *Transportation Research Part A: Policy and Practice*, *67*, 110-126.
Summary	The paper investigates mode preference evolution and mode forecasting performance using 1996, 2001, and 2006 TTS data. The nature of the TTS datasets allowed the authors to capture temporal aggregate structural changes in commuting mode preferences sensitive to spatial variability.
Potential Applications	• The paper presents a more optimal approach of identifying changing modal preferences over time through the statistical analysis of repeated cross-sectional data
Strengths	• Provides a methodology for the assessment of mode choice using repeated cross-sectional data
Weaknesses	• Assesses mode choice based on repeated cross-sectional data consisted of three waves as opposed to daily repeated cross-sectional data; the current proposed form

Title	**Use of repeated cross-sectional travel surveys to develop a Meta model of activity-travel generation process models: accounting for changing preference in time expenditure choices**
Author(s)	Salem, S., & Nurul Habib, K. M.
Citation	Salem, S., & Nurul Habib, K. M. (2015). Use of repeated cross-sectional travel surveys to develop a Meta model of activity-travel generation process models: accounting for changing preference in time expenditure choices. *Transportmetrica A: Transport Science*, *11*(8), 729-749.
Summary	The paper investigates the temporal transferability of activity generation models using classical cross-sectional and repeated cross-sectional datasets. The waves of TTS data are used for the analysis; 2001, 2006 and 2011. Models are developed for each cross-sectional year and then for the pooled cross-sectional data of the three TTS waves.
Potential Applications	• Provide a comparison between classical cross-sectional data and repeated cross-sectional data for activity generation models
Strengths	• Illustrate a methodology of using repeated cross-sectional data for modelling activity generation • Two different models are estimated using repeated cross-sectional data – a worker and non-worker model.
Weaknesses	• The nature of the repeated cross sectional data are not similar to that collected using a day-to-day continuous survey. Therefore, different aggregation schemes will have to be developed.

Title	**Sydney Strategic Travel Model (STM) - Modelling future travel patterns**
Author(s)	Bureau of Transport Statistics – Sydney, Australia
Citation	Bureau of Transport Statistics (2011). Sydney Strategic Travel Model (STM) - Modelling future travel patterns. Technical Documentation. NSW: Sydney, Australia.
Summary	A technical report issued by a government authority describing the Sydney Strategic Travel Model (STM).
Potential Applications	• Understand how a mode-destination choice model may be carried out using continuous data
Strengths	• Talks about the potential of the model
Weaknesses	• Does not discuss the process of aggregating the data and feeding it into the model

Title	**Household Travel Survey 2011/12**
Author(s)	Bureau of Transport Statistics – Sydney, Australia
Citation	Bureau of Transport Statistics (2013). Household Travel Survey 2011/12. Technical Documentation. NSW: Sydney, Australia.
Summary	A technical report that documents the survey methodology, weighting, pooling and estimation techniques of Sydney's HTS.
Potential Applications	• Provide greater insight on the process of data collection, handling and validation of a continuous survey
Strengths	• Provides an adequate explanation on the processes of weighting, expansion, pooling and validation
Weaknesses	• Does not discuss the methods of aggregation used to pool data • Does not discuss how a trip matrices or mode-destination choice models may be estimate using continuous data

10 APPENDIX B: UPDATING O/D MATRICES USING CONTINUOUS DATA

- Construct the OD matrix for each year of continuous data using the fall period only
- Calculate the mean absolute percentage error MAPE of each OD matrix (for every year)

$$\text{MAPE}_{ij} = \frac{\sum_i \sum_j \text{APE}_{ij}}{N} \qquad \text{APE}_{ij} = \left| \frac{A_{ij} - E_{ij}}{A_{ij}} \right| \times 100$$ [3]

Where:

A_{ij} = population count for the morning commute from origin i to destination j

E_{ij} = expanded sample count for the morning commute from origin i to destination j

N = total number of OD cells

The population count for the morning commute can be obtained using loop detectors on highways

- Sum up the error values to get a total "ε "
- Divide the error value ε_i for each year *i* by the total error value ε , such that $\sum_{i=1}^{n} \varepsilon_i{}' = 1$
- Adjust the OD matrices trip counts by multiplying the yearly error values by their respective OD matrices
- Sum up all the OD matrices over a 5 year period to construct an OD matrix similar to that of a 5% cross sectional TTS[4]

$$\sum_{i}^{n} (\varepsilon_i' * OD_i) = OD\ over\ a\ 5\ year\ period$$

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[3] The MAPE and APE formulas were obtained from (Cools, et al., 2010)

[4] This exercise assumes a fall-yearly repeated cross-sectional of a sampling rate equal to 1%