CURRENT STATE OF LANDLINE SURVEY METHODS

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Transportation Tomorrow Survey 2.0

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1 INTRODUCTION

The Transportation Tomorrow Survey (TTS) is a regional household travel survey that is administered once every five years on behalf of "local, regional, provincial, and transit operating agencies in the Greater Toronto and Hamilton Area (GTHA)". The 2011 TTS, the most recent survey, surveyed 159,157 households (comprising 5% of the Census households in the GTHA) that gathered information on approximately 860,000 trips. (Data Management Group, 2014)

The TTS, like most major transportation surveys is a landline based survey where respondents answer questions through a Computer Aided Telephone Interview (CATI). The TTS, as with most current landline based surveys, suffers from a common set of issues that raise a few interesting research questions that are highlighted in the TTS2.0 Research Plan:

- As landlines become less common, the utilization of a landline directory becomes less and less representative of the population and results in the underrepresentation of younger members of the population, students, and seniors (New York Metropolitan Transportation Council , 2014). Can listings of mobile phones be used to augment land-line frames in a joint frame that would provide a representative sample of the study area population?
- Shorter and non-motorized trips are undercounted as respondents either forget shorter trips or the survey ignores non-motorized links of motorized trips. (Iacono, et al., 2010)
- Can a stratified sampling strategy reduce the overall sample size of the TTS while at the same time helping to address the under-sampling of hard-to-reach groups such as the 18-32 age group?
- The use of a single respondent generates well-known under-reporting of trips by household non-respondents. Are there ways of reducing this proxy/non-respondent bias?
- The respondent burden associated with a telephone interview leads to survey groups limiting the scope of questions asked in the survey in order to prevent response rates from reducing. Can intelligently designed satellite surveys administered to smaller sub-samples augment core surveys and gather a richer set of data that would otherwise have been impossible with the traditional TTS?

This report aims to answer the above questions based on an extensive literature review of the current state-of-the-art in terms of landline surveys around the world. In addition to various small-scale surveys carried out and published in journal articles, 6 recent major public surveys were examined:

- 2013 California Household Travel Survey
- 2010/11 New York Regional Travel Survey
- 2012 Utah Travel Study
- 2007/08 Washington Regional Household Survey
- 2014 Vancouver Panel Survey
- 2014 Edmonton Household Survey (Pilot for the full-scale 2015 survey)

A comparison of the above surveys to the 2011 TTS with brief available statistics and sampling frame information is provided in the table and graphs below:

TABLE 1: SELECT STATISTICS AND SAMPLE FRAME INFORMATION OF MAJOR REGIONAL TRANSPORTATION SURVEYS REVIEWED

	Method of contact	Sampling Frame Type	No. of sampled households	No. of recruited households	Response rate
2011 TTS	Mail invitation - Provide online link and call Landline	Address based sampling	416,917	159,157	48.9%
2013 California Household Travel Survey	Mail invitation - Provide online link and call Landline	Address based sampling	2,120,720	63,082	2.0%
2010/11 New York Regional Travel Survey	Mail invitation - Provide online link and call Landline	Address based sampling	711,551	31,156	4.2%
2012 Utah Travel Study	Mail invitation - Provide online link and call Landline	Address based sampling	124,888	9,155	7.30%
2007/08 Washington Regional Household Survey	Mail invitation - Provide online link and call Landline	Address based sampling	141,050	14,967	10.6%
2014 Vancouver Panel Survey	Mail invitation - Provide online link and call Landline + Cell-phone	RDD Landline + RDD Cell-Phone	N/A	2533	Not provided
2014 Edmonton Household Survey (pilot for 2015 survey)	Mail invitation - Provide online link and call Landline	Address based sampling	3,975	203	5.1%

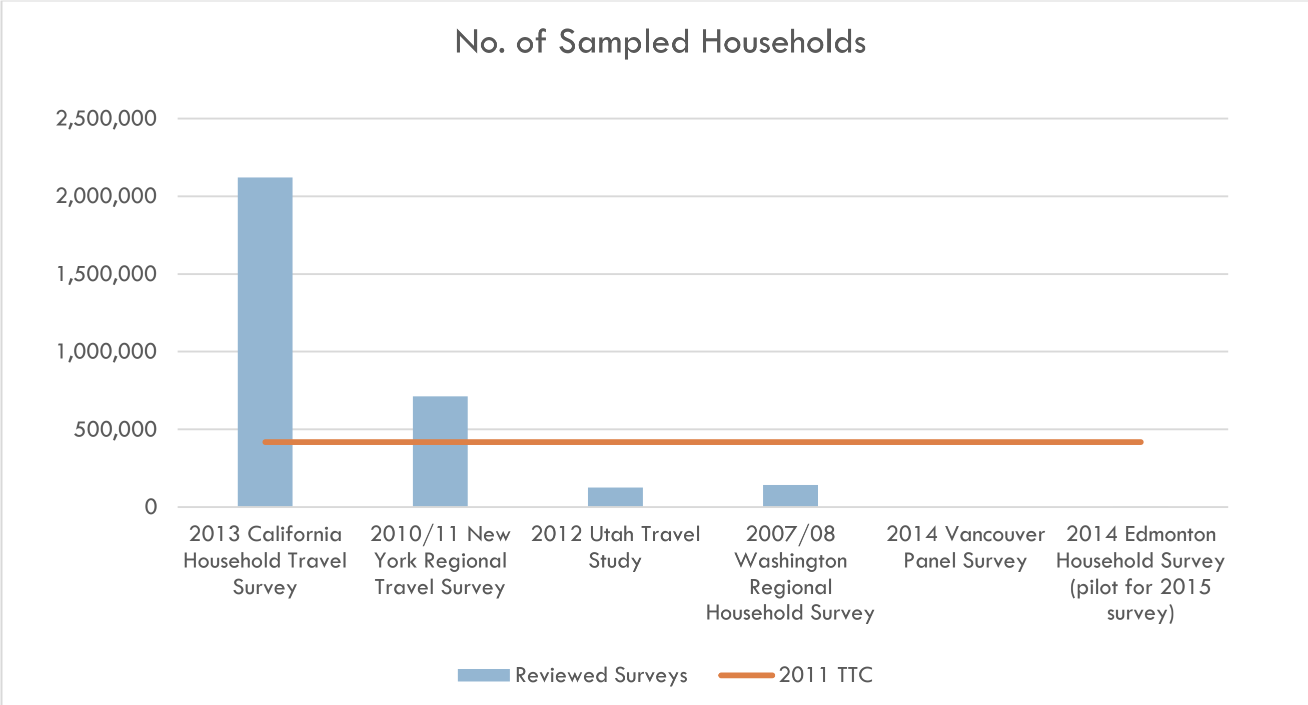

FIGURE 1: COMPARISON OF NO. OF SAMPLED HOUSEHOLDS IN REVIEWED SURVEYS

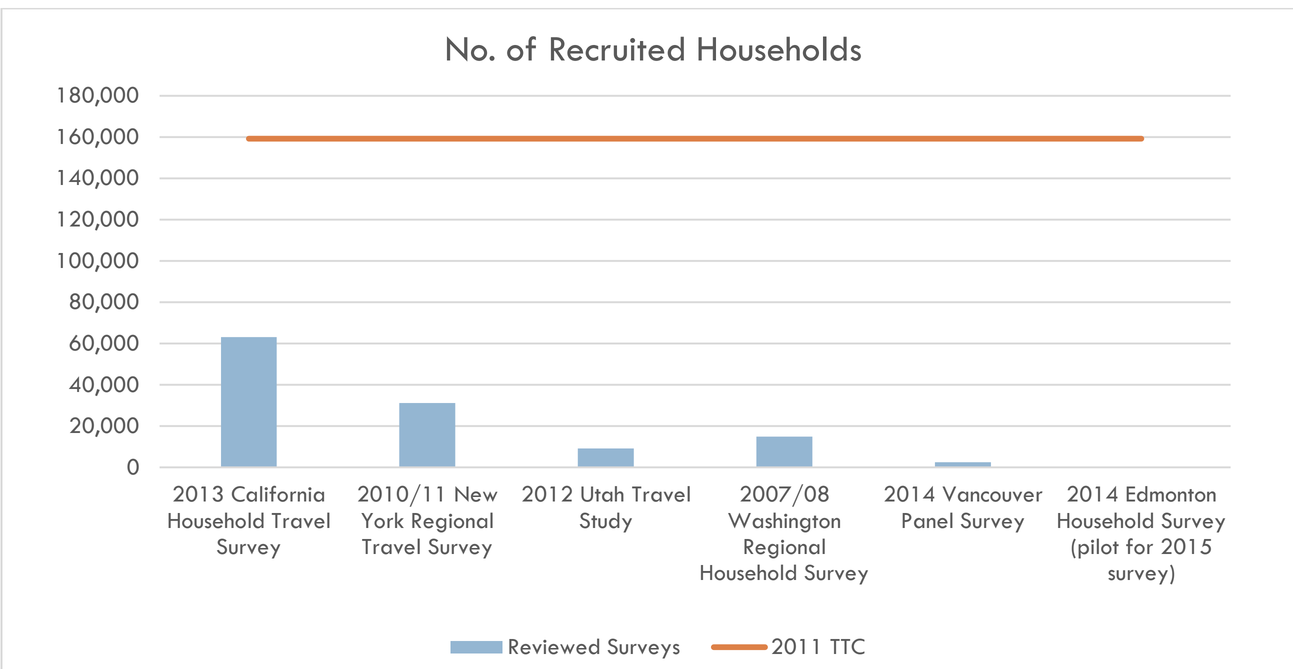

FIGURE 2: COMPARISON OF NO. OF RECRUITED HOUSEHOLDS IN REVIEWED SURVEYS

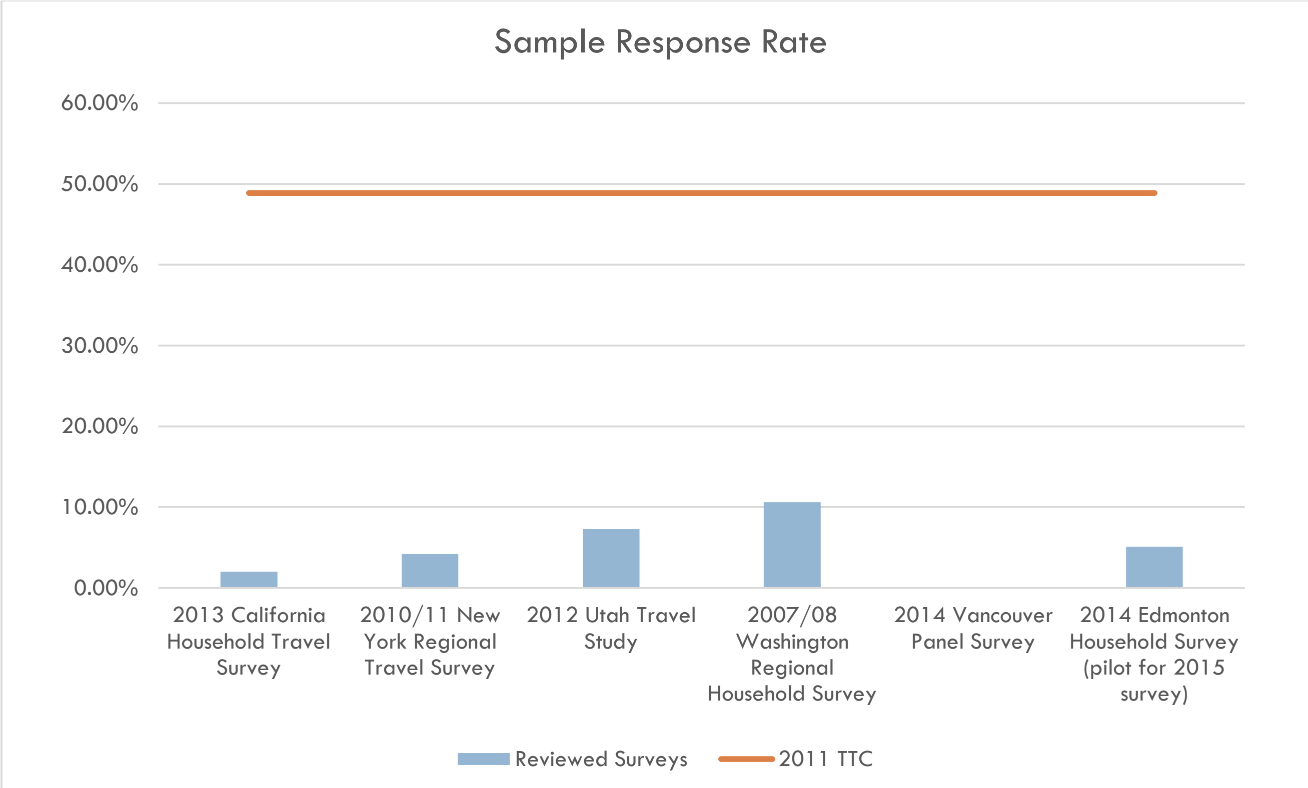

FIGURE 3: COMPARISON OF SAMPLE RESPONSE RATES IN REVIEWED SURVEYS

The rest of this report is structured in the following manner. Section 2 details the concept of a joint land-line and cell-phone sampling frame, its deployment in reviewed surveys and the unique challenges arising from such a solution. Section 3 discusses the problem of under-reporting of non-motorized travel in regional household travel surveys and the various solutions employed by reviewed surveys. Section 4 discusses the strategy of stratified sampling and its usefulness as a tool to reduce overall size of the survey, while providing a representative sample of the study area population. Section 5 discusses the problem of bias in proxy reporting, a common occurrence in household travel surveys where the individual who completes the survey provides the trip information for all members of the household. Section 6 discusses the emerging implementation of the core-satellite paradigm, where separate distinct and small surveys are carried out in addition to the main survey, in order to either gather a richer set of data or to solve one of the issues faced by landlines detailed above.

At the end of each of these sections is a Highlights and Recommendations section that details the most important points from that section and related recommendations for the TTS2.0 pilot to be implemented in 2016. Finally, Section 7 gathers all the pilot recommendations that arise based on this literature review.

A quick summary of the solutions implemented by each of the reviewed major public transportation surveys (California, New York, Washington, etc.) for each of the problems detailed in Sections 2-6 is provided in the table below:

TABLE 2: SUMMARY OF STRATEGIES AND METHODS EMPLOYED IN VARIOUS RELEVANT SURVEYS

	Estimating under-reporting of non-motorized modes	Proxy policy	Stratification Strategy	Satellite Surveys conducted
2013 California Household Travel Survey	GPS sub-sample for underreporting	Call-back method: Atleast 3 call attempts until proxy is allowed	30 regional strata for address based sampling	(1) Listed telephone numbers from US working numbers to survey hard-to-reach Hispanic populations (2) GPS sub-sample for underreporting
2010/11 New York Regional Travel Survey	GPS sub-sample for underreporting	Call-back method: Atleast 3 call attempts until proxy is allowed	Stratified by 28 counties	GPS sub-sample for underreporting
2012 Utah Travel Study	N/A	Proxy responses allowed	Stratified by 7 regions	(1) College Student Diary (2) Long Distance Travel Survey (3) Attitudes and Opinions Survey (4) Bike/Walk Debrief Survey (5) Bike/Walk Barriers Survey (6) Residential Choice Stated Preference Survey
2007/08 Washington Regional Household Survey	GPS sub-sample for underreporting	No proxy allowed for first 3 days	42 geographic strata and 2 area types - high density mixed use and low-density	GPS sub-sample for underreporting
2014 Edmonton Household Survey (pilot for 2015 survey)	N/A	N/A	N/A	N/A
2014 Vancouver Panel Survey	N/A	N/A	Stratified by City's 9 transportation zone designations	Address-based sampling with post card invitations for residents in False-Creek as they had very low response rates in 2013 landline survey

2 JOINT CELL PHONE AND LANDLINE SAMPLING FRAMES

Survey methodology is based on the concept of probability sampling, which allows one to make inferences about large populations without observing every single member. To draw a probability sample from a population, it is necessary to have a list or selection process, called a sampling frame, that ensures some probability of selection for each element in the population (Warnecke, 2005). The sampling frame defines the portion of the population from which the sample is selected. Hence, the quality, completeness and availability of possible sample frames are major considerations when selecting a population for study using statistical inference.

Frames are usually defined by geographic listings of blocks, units, maps or memberships; they may also be defined from telephone or other electronic formats. Ideally, a frame's specifications should define the geographic scope of the survey, categories of material covered and any auxiliary information (measures of size and demographic information) that might be used for stratification or other special sampling techniques.

In most countries where there is extensive telephone coverage, telephone interviewing has become the sampling technique of choice because of cost and problems associated with accessibility of respondents for face-to-face interviews. Traditionally, telephone directories have not been used for frames when they are incomplete, and as such, random digit dialing (RDD) have been most commonly used (Warnecke, 2005). The frames for RDD are constructed by random selection of ten-digit numbers comprised of the area code, prefix, and suffix of individual telephone numbers. These can be additionally have been screened to only include working numbers.

However, households have been documented as being increasingly equipped with cell telephones, with or without traditional landline phones. In Canada, 83% of households had an active cell phone in 2013, up from 78% in 2010 (Statistics Canada, 2014). Conversely, the proportion of households with a landline phone is decreasing. In 2013, 21% of households reported using a cell phone exclusively, up from 13% in 2010. Exclusive cell phone use is more pronounced in young households where all of the members are under 35 years of age. In 2013, 60% of these households reported using a cell phone exclusively, up from 39% in 2010 and 26% in 2008. (Statistics Canada, 2014)

Although exclusive cell phone use is less common in households composed only of those aged 55 and over, it is on the rise, up from 2% in 2008 to 6% in 2013. Therefore, traditional Random Digit Dial (RDD) telephone surveys, which were based on samples of landline telephone numbers, are increasingly at risk of bias for omitting households that do not have a landline phone. (Statistics Canada, 2014)

One alternative approach is to supplement a landline sample with a sample of cell telephone numbers so that all households with any phone have a chance of selection in RDD surveys. The major issue with developing such a joint telephone and cellphone frame in Canada is that there is no listed cell-phone database available from where a representative sample of numbers can be extracted to contact respondents (Public Works and Government Services Canada, 2014). Only Vancouver was found to append random-digit cell phone numbers generated within City rate centres to the overall joint survey frame for transportation surveys (CH2MHill, 2015).

Another, more popular, alternative is to begin with a sample drawn from a frame of addresses, where the type of telephone coverage is not a coverage issue. Address based sampling (ABS), discussed extensively by Iannacchione (2011), has been used for many years for mail surveys and face-to-face surveys. A current listing of city and rural route residential postal addresses for the study area is typically purchased from survey houses or obtained from Census master address file information. Using the address–based frame, addresses are typically matched to landline telephone numbers for proactive contacting of prospective respondents (Iannacchione, 2011). This preliminary matching process resulted in two types of sample households: (1) households that could be matched to a landline telephone number and (2) households that could not be matched. The latter samples that could not be matched to a landline telephone number are called “Unmatched Households,” which includes non–telephone and cellphone–only households (California Household Travel Survey, 2013). These unmatched households are then sent a postal mail to their address asking them to either complete the survey by mail or online, or to return the mail with their relevant cell-phone contact information. This cell-phone information is then used to conduct the survey, and also stored for creating future sampling frames. Unmatched households are typically offered a monetary incentive to participate due to increased respondent burden, and also due to historical low response rates owing to the mode of contact (postal mail) (National Capital Region Transportation Planning Board, 2010; New York Metropolitan Transportation Council , 2014). Most surveys studied followed the address-based sampling method outlined above – these included regional household travel surveys in New York, Washington, California and Utah, among others.

2.1 Current state of Cell-Phone Sampling in Canada

The majority of sample providers do not appear to have entered the cell phone market in Canada. According to the listing of sample providers registered with the Marketing Research and Intelligence Association (MRIA), there are two that have done work in cell-phone listings in Ontario – SM Research (Sampling Modelling & Research Technologies) and Survey Sampling International. (Marketing Research and Intelligence Association, 2015)

In terms of sample frame construction (outside of address-based sampling), there are several ways in which cell phone sample frames can be constructed—RDD, pre-screened cell phone numbers, and cell phone only households. Each approach has its own methodological issues and cost implications. It is important to note that the sample frames listed in this section are ones that have been successfully implemented in the USA and elsewhere, but have not necessarily been implemented to date in Canada. As mentioned earlier, only two firms so far have penetrated the cell-phone sampling market in Ontario.

The least expensive cell phone sample available for purchase are RDD sample frames. Since directories of current cell phone numbers do not fully exist, cell phone sample frames are generated based on the list of existing dedicated cell phone exchanges in Canada. Some firms, for example, break cell phone exchanges into blocks of 100 numbers, weight the sample by geography, and then calculate the quantity of numbers needed per block. The final numbers are randomly selected via a computer program. The typical connection rate is 50-55%. (Public Works and Government Services Canada, 2014) These samples will include CPO (cell-phone only) households and dual phone users (cell and landline households).

The administrative information available with these sample frames is limited to the area code and the rate center. This means that the cell number can be linked to a province and the city in which the phone exchange switching station is located, and this information can be combined to link the number of a Census Division (CD) in Canada. The numbers cannot be linked to smaller geographical areas, like a census subdivision (i.e., a municipality). If weighting to a lower geographic level—e.g., city level—is needed, additional data, needs to be collected from respondents. However, even this level of geocoding is becoming less accurate as people are increasingly choosing numbers based on convenience. Thus, for instance, people living outside Toronto continue to use area code (416) numbers for their cell-phones. (Christian, et al., 2009)

Another option when it comes to cell phone samples is a sample frame of 'working' cell phone numbers. Some firms maintain a database of pre-screened working cell phone numbers. These numbers have been 'predialled' and the Not in Service (NIS) records removed. Unlike RDD samples, the numbers purchased are guaranteed to be working cell-phone numbers. On the flip side, this approach is more expensive and the numbers cannot necessarily be linked back to the Census Division to get geographical information. In addition, since the sample is not random, the results cannot be considered to be probability-based due to self-selecting for a specific set of working numbers.

Finally, if it is desired to reach the demographic that is missed most often in land-line based surveys (i.e. the young, urban dwellers), the goal should be to contact cell-phone only households (CPOs). CPO samples can be compiled from a database of working cell numbers. This is the most expensive option, as further screening needs to be conducted to filter the CPO households from the working cell number database. However, this screening done upfront results in a shorter interview, as the respondents do not need to be asked whether or not they belong to a CPO household. Again, as this frame comes from a working cell number database, it is not a random sample and thus the results cannot be projected to the general populace. (American Association for Public Opinion Research, 2010)

As such, when conducting dual frame telephone-cell phone surveys for the pilot, the decision on which method to use is dependent on the budget for the pilot survey. Given limited time and resources, RDD sample frames should be preferred. Not only are they the least expensive alternative, but since the phone numbers obtained are random, the results of the survey can be projected to the target population. The drawback of a slightly longer interview is not a significant enough deterrent to make the other alternatives more attractive.

2.2 Sample overlap in joint landline and cell-phone frames

By definition, a landline sample and a cell phone sample overlap for respondents in households with both landline and cell phones. Two different approaches have been used to handle the overlap: the screening approach and the overlap approach.

In the screening approach the interviewers terminate interviews with cell phone respondents who have at least one landline phone in the household and, therefore, could potentially be reached through the landline sample frame. These individuals will be eligible only when sampled from the landline frame. Smaller surveys, such as the CELLA1 Survey in Germany, utilized this screening approach (Mario Callegaro, 2011). The screening approach may not be appropriate for lengthy surveys, as it raises respondent burden by making the survey more cumbersome. In addition, it would require the interviewers to contact the respondent once again on their landline, which also raises the cost.

In the overlap approach, the interview is conducted regardless of the frame from which the respondent is selected (landline or cell). If they were randomly selected in both frames, information about their phone ownership status in both frames is collected. The 2014 Vancouver Transportation Panel Survey, the only major transportation survey that used a joint cell-landline frame, utilized this overlap approach (CH2MHill, 2015). The overlap approach is typically advantageous if there is a fundamental assumption that the probability of a respondent being randomly selected in both frames is negligible. Even then, the Vancouver survey, at 2500 respondents is very small compared to the TTS. Within the TTS, we can reasonably expect to encounter households contacted in both frames, thereby reducing the advantage provided by the overlap approach.

However, within a RDD joint-sample frame that utilizes the overlap approach, when sample frame overlap does happen, the households in the overlap are double-covered since they could have been selected from the landline frame or the cell phone frame. Without a weight adjustment, our estimate of households in the overlap will be double the appropriate estimate.

The 2014 Vancouver Panel Survey did not have any significant overlaps between landline and cell-phone respondents. This was mainly because the respondents who had access to and were contacted by the cell-phone option were of a different demographic than the ones who had access to and were contacted by the landline option. For instance, of the total diaries completed by those within the 15-34 age cohort, 50% were recruited via the cell-phone sample, compared to only 9% via landline. (CH2MHill, 2015)

The 2009 Minnesota Health Access Survey, which used a dual landline and cell-phone frame, adjusted weights in sample overlaps by multiplying the weights in one sample (landline in this case) by a weighting adjustment factor λ, and multiplying the weights in the other sample (cell phone in this case) by (1-λ). (Xia, et al., 2010) This is often referred to as composite weighting and corrects the double-counting problem. Even though respondents in the overlap still have a chance to be in either the landline or cell phone samples, their weights are corrected so that their phone usage category is not overrepresented through the weights.

There are a few options for what λ should be, and each of the options has its own limitations and advantages:

Option 1: Set λ=0.5

This is the simplest assumption possible. This method assumes that, like a household with two landline telephones, a household with a landline phone and a cell phone should have its weight divided by two because of the doubled chances of inclusion. However, this assumption will lead to inefficiency if the probability of selection is much different for an overlap case in the landline and cell phone samples.

Option 2: Sample Size

This method calculates λ proportional to the sample size in the landline sample. The logic of this choice is that the landline and cell phone surveys are both trying to represent the same population of households. Ignoring under-coverage (of cell-only households in the landline frame and landline-only households in the cell phone frame), if the landline and cell phone samples have different sizes, the sample with the smaller sample size will tend to have larger weights. This method will reduce the larger weights from the smaller sample more than the smaller weights from the larger sample. In the 2009 MNHA, the landline sample size was larger so the λs were all greater than 0.5.

$$\lambda = \frac{n_L}{n_L + n_C}, \tag{1}$$

where n_L is the landline sample size in the overlap, and n_C is the cell phone sample size in the overlap.

Option 3: Effective Sample Size

This option adds another consideration to option 2: the variance in weights among the two samples being combined. Option 2 assumes that if the sample sizes are even, the optimal λ is 0.5, but this option considers the estimated information gained from each sample rather than just the sample size. When the weights are more variable, the information is less per completed interview. This option adjusts λ to measure the estimated information gained from each sample rather than just the sample size. This method calculates λ proportional to the estimated effective sample size in the landline sample. (Pedlow & O'Muircheartaigh, 2002)

$$\lambda = \frac{\frac{n_L}{d_L}}{\frac{n_L}{d_L} + \frac{n_C}{d_C}}, \tag{2}$$

where

d_L is the design effect due to weighting in the landline sample

d_C is the design effect due to weighting in the cell phone sample

And d_L and d_C can be estimated by

$d_L = 1 + (CV)^2$ for landlines

$d_C = 1 + (CV)^2$ for cell-phones

Finally, CV is the coefficient of variation, which is the standard deviation of the weights divided by the mean of the weights.

2.3 Determining sample sizes for the joint landline and cell phone frames

In the 2014 Vancouver Transportation Panel Survey, the proportion of respondents chosen from cell-phone samples was based on their direct proportion in the general population (CH2MHill, 2015). A similar approach was used in the 2009 Minnesota Health Access Survey (Xia, et al., 2010). However, these two surveys, at sample sizes of 2,500 and 10,000 approximately, are relatively small when compared to the TTS. In larger surveys, the cost of surveying becomes an important consideration to set sample size. Outlined below is a theoretical approach to optimizing the cost of a dual frame survey, as detailed by Hu et. al in *Improving Public Health Surveillance Using a Dual-Frame Survey of Landline and Cell Phone Numbers*: (Hu, et al., 2011)

The population of adults living in households with telephone service can be divided into 2 primary strata: landline and cell-phone-only. Although the majority of the adult population is contained in the landline stratum, the proportion of the population in the cell-phone-only stratum has been rapidly growing. Several factors, including screening, make the cost of a cell-phone-only interview higher than that of a landline interview. The allocation of the total sample to the 2 strata can be determined using the optimum allocation method, which seeks to minimize the variance for a specified total cost.

The optimum allocation, in terms of the proportion of the total sample that should come from the cell-phone-only stratum, can be expressed as:

$$\frac{\rho}{\rho+(1-\rho)\sqrt{\frac{c_{cell-only}}{c_{landline}}}} \tag{3}$$

In this formula, ρ is the estimated proportion of adults in the survey target population that use only a cell phone, $c_{cell\text{-}only}$ is the cost of conducting a cell-phone-only interview, and $c_{landline}$ is the cost of conducting a landline RDD interview.

Based on the 2007 Behavioural Risk Factor Surveillance System pilot study and other cost estimates that have been reported, the cost ratio of $c_{cell\text{-}only}$ to $c_{landline}$ is approximately 5. (Center for Disease Control and Prevention, 2007)

2.4 Challenges associated with Cell Phone Surveys:

Survey researchers who sample cell phones face a set of legal, cost, safety and privacy issues that are different from those associated with sampling landlines. In the United States, the Telephone Consumer Protection Act prohibits the use of an auto-dialer with cell phones, unless there is prior consent. In Canada, there are no comparable laws (Public Works and Government Services Canada, 2014). Legal issues include being in compliance with restrictions on calling cell phones (if any exist), text messaging, and spam, as well as considering the possible implications of such laws.

A second issue deals with the charges associated with the telephone call. In the US and Canada, most calls to a cell phone incur a cost to the wireless service subscriber, thereby increasing respondent burden. One way to deal with this issue is to reimburse or compensate respondents for the call, a procedure adopted for the 2004 Practicum Survey.

The key safety concern posed by cell phone surveys is that the respondent may be involved with other activities, such as driving a car, which require full attention. The procedures developed to deal with this involved training interviewers about the problem and offering a callback in these cases. Additionally, items to assess the nature of this problem were included in the interview itself. In terms of privacy, since the cell phone is viewed as a personal device by many users, calls to the phone by strangers may be more of a concern than on landlines.

Another related concern raised is that wireless conversations are not as secure as those over a landline because it can take place in a public place and, thus, may not be as confidential. Many of these issues are discussed by Steeh et.al, who provided guidance on survey procedures. (Steeh, et al., 2004)

Finally, cell phone lists do not contain the home location of cell owners, but only the location where the cell-phone was purchased. As such, it is expensive and difficult to target geographic transportation zones based on cell phone samples for younger age groups, as they are the most mobile and hard-to-reach demographic. Also, the most common stratification strategy for overall household surveys is to divide the respondents into distinct geographic strata. Given incorrect geographic locations based on cell-phone area codes, a cell-phone sampling frame provides additional challenges to implementing this strategy. (CH2MHill, 2015)

2.5 Design considerations for cell-phone samples

According to the American Association for Public Opinion Research (AAPOR), there is no widely-recognized formal best practices in the area of cell phone survey research. However, they suggest that the following issues be given consideration when designing a telephone survey project: (Lavrakas, 2010)

Coverage and Sampling: Including an RDD cell phone frame in a telephone survey minimizes the potential for error resulting from inadequate coverage of the target population with a RDD landline sampling frame. When it comes to coverage, and the potential benefit of including cell phones when surveying the general public, there are several key issues that should be given consideration during the design phase. Researchers need to decide whether the dual frame design will be overlapping (i.e., with no screening for landline telephone service and usage) or non-overlapping (i.e., screening cell phone sample for CPO households).

An overlapping approach is less expensive, but requires the construction of a more complicated weighting scheme to reflect the multiple probabilities of respondent selection. This is further complicated by the issue of dual cell and landline users. Studies suggest that 'wireless-mostly' and 'landline-mostly' individuals have different response propensities depending on which service they are contacted for a survey. This can lead to differential non-response, and biased survey results, if such differences are not accounted for in the weighting scheme.

A non-overlapping approach makes weighting much simpler post-data-collection, but is a far more expensive option given the relatively low incidence of CPO households (estimated to be less than 15% in Canada at this time).

Consideration should be given to the purchasing of the cell phone sample. A number of issues are identified by AAPOR: how the sample provider's frame has been constructed, how often the frame is updated, the types of wireless services included (e.g., dedicated, shared, special billing), the extent of non-coverage and overlap between the provider's landline and cell frames, how shared service numbers are handled, and the levels of geography available for sample selection and how they have been determined.

Sample allocation is another decision to be made by researchers—that is, the relative proportions allocated to the cell phone and landline frames. In terms of guidance, AAPOR suggests that enough interviews be completed with the cell phone sample to avoid the need for large weights. (Refer to previous sections in this report on how international survey vendors handle sample allocation)

Within-household sampling is another issue that should be considered when conducting cell phone research. A RDD telephone survey typically uses the 'most recent birthday approach' to randomize respondent selection within a household. When a potential respondent is reached on a cell phone, the interview is typically conducted with this person, provided that the individual meets the study's eligibility criteria, because any attempt at respondent selection may result in a refusal. In the U.S., most organizations treat cell phones as personal, not household, devices.

Questionnaire Length: Questionnaire length is an important consideration for all survey research. However, it takes on even more importance when dealing with a cell phone sample frame. While evidence tends to be anecdotal, some researchers report that cell phone respondents are more difficult to keep on a call than respondents on landlines (i.e., respondent break-offs). Respondents speaking on their cell phone may be more easily distracted—for instance, they may be engaged in other activities like driving, shopping, or exercising. In addition, because of the mobile nature of cell phones, respondents' environments may change during the course of an interview. They may go from having no distractions to many, or from a safe environment to one where their personal safety (e.g., driving) or confidentiality (i.e., from a private to a public space) may be at risk during the interview. Given these concerns, AAPOR suggest that researchers may want to consider whether the length of an interview conducted on a cell phone should be shorter than one conducted on a landline.

Remuneration: The issue of remunerating cell phone respondents stems from the ethical concern that researchers not do any harm to a respondent, including not causing the respondent to bear any financial burden on behalf of the researcher. Given the nature of cell phone billing (i.e., some plans bill customers by the minute), there may be a financial burden associated with responding to an incoming survey research call. When appropriate, these associations suggest that researchers give consideration to offering some form of remuneration to eliminate, or offset, the potential financial burden of participating in a survey.

Cost: The cost and anticipated benefit(s) of including a cell phone sample in a telephone survey should be carefully considered by researchers. Including a cell phone sample can be expensive (especially when targeting CPO households—i.e., using a non-overlapping sample frame approach), and the cost of doing so, may not justify the perceived benefits of greater coverage. The Pew Research Center has found that it takes roughly 60% more working numbers to complete an interview with the cell phone sample. This is due, in large part, to higher ineligibility rates (e.g., ineligible minors).

2.6 Highlights and Recommendations:

- In Canada, 83% of households had an active cell phone in 2013, up from 78% in 2010. In 2013, 21% of households reported using a cell phone exclusively, up from 13% in 2010. Therefore, traditional Random Digit Dial (RDD) telephone surveys, based on samples of landline telephone numbers, are increasingly at risk of bias for omitting households that do not have a landline phone.
- The major issue with developing such a joint telephone and cellphone frame in Canada is that there is no listed cell-phone database available from where a representative sample of numbers can be extracted to contact respondents.
- Of city-wide surveys, only Vancouver utilizes RDD sampling.
- Most surveys studied follow the address-based sampling method – these include regional household travel surveys in New York, Washington, California and Utah, among others.
    - Recommendation: Use Address-based sampling for the TTS pilot – given higher accuracy and quality of the frame. Provide the respondent with multiple options to contact the interviewer – online survey link, landline telephone interviewing and an option to send cell-phone contact information back to the interviewer.
- If RDD is chosen, there are 3 options to purchase sample frame. Cheapest is traditional RDD frames, followed by pre-screened 'working' cell phone numbers, and finally cell-phone only households that are further screened.
    - Recommendation: If going down the RDD route, for overall core survey choose traditional RDD frames. Create a satellite survey of cell-phone only households to target hard-to-reach groups such as the 15-31 age groups.
- Two different approaches to deal with sample overlap in joint frames – (1) screening, where interviews with cell-phone respondents are terminated if they have a landline (2) overlap, where interview is conducted regardless of instrument ownership
- Screening approach is expensive as the survey becomes longer due to additional questions and interviewers being required to contact the respondent once again on the landline. Overlap approach is cheaper but requires a weighting system if there is a high probability of a respondent being chosen in both landline and cell frames.
    - Recommendation: Utilize a screening approach for the pilot and the main survey as well. Screening is simpler and allows for data integrity as the respondent only gives information once (do not terminate the call if the respondent is also selected on an alternate frame, instead remove the respondent from those other frames after their travel information is collected)
- Cell phone and landline sample sizes are typically dependent on their overall proportion of usage in the general population. Vancouver and Minnesota both choose sample sizes based on this calculation.
    - Recommendation: If the cost of a landline and cell phone interview differ a lot, allocate the total sample to the 2 strata based on the optimum allocation method.
- Cell phone lists do not contain the home location of cell owners, but only the location where the cell-phone was purchased. As such, it is expensive and difficult to target geographic transportation zones based on cell phone samples for younger age groups, as they are the most mobile and hard-to-reach demographic.

3 NON-MOTORIZED MODES

Household regional travel surveys provide critical data inputs for transportation planning, decision making and policy making. While improvements have been made in the type of trip information captured in household travel surveys, pedestrian and bicycle trip data are often underreported or inaccurate, and often lacks an adequate sample size to provide useful information. The exclusion of supplementary non-motorized trips in the travel and census surveys results in an underestimation of non-motorized modal share, usually ranging from 5% to 10% (Sallis, et al., 2004)

The 2011 New York Regional Household Travel Survey found that almost all of its underreported were non-motorized. This level of underreporting in the survey was calculated to be 18%, with the GPS sub-sample showing a mean of 12 daily trips per participant, while the larger non-GPS core sample showed a mean of 9.7 daily trips per participant (New York Metropolitan Transportation Council , 2014). The underreported share of non-motorized trips also leads to the lack of sufficient data for estimating statistical models specifically developed for non-motorized travel.

Better non-motorized data allows policy makers and local communities to add pedestrian and bicycle travel to regional transportation models, understand how far people typically walk and bike for different purposes, and promote connectivity of non-motorized facilities with other modes of transportation. Though few previous household travel surveys have captured comprehensive pedestrian and bicycle trip information, household travel surveys have high potential to collect non-motorized transportation data from a representative sample of the population. Several communities have distributed pedestrian and bicycle surveys to trail users and people walking or bicycling in parks or shopping districts, but these surveys only capture people who are already walking and bicycling; they are not a representative sample of the population. Pedestrian and bicycle counts are taken in some communities, but they also represent trips in a limited sample of locations, not the travel behaviors of an entire region.

3.1 Why are non-motorized trips underreported?

Most travel surveys undercount shorter and non-motorized trips due to the following factors: (Forsyth, et al., 2010)

- Older surveys were designed primarily to provide data for traffic models, and so only counted peak-period trips between Traffic Analysis Zones (TAZs). They ignored shorter trips within TAZs, and off-peak trips.
- Many surveys ignore non-motorized links of trips that include motorized travel. For example, a bike-bus-walk trip is coded simply as a transit trip, and walking links between parked cars and destinations are not counted even if they are several blocks in length. For example, although only 7% of Canadian urban commutes are entirely by walking, about 20% include a walking link, and in German cities, although only 22% of trips are completely by walking, 70% include walking links. If, instead of asking "what portion of trips involve only non-motorized travel", we ask "what portion of trips involve some non-motorized travel", 20-30% of non-motorized urban trips would be included and active modes would be recognized as common and important. (Litman, 2014)
- Some travel surveys only count commute trips, and many ignore travel by children, and recreational travel.
- Survey participants often have trouble remembering and recording shorter trips.

3.2 Estimating Level of Under-reporting of Non-Motorized Travel

3.2.1 Satellite GPS Sub-samples

With the growing popularity of the core-satellite survey paradigm, many recent household transport surveys have endeavoured to better understand and quantify the under-reporting of non-motorized trips, and even all trips in general, within their study areas. The most popular solution, which has been seen in the California, New York and Washington surveys, has been to provide a sub-sample of the core sample with wearable GPS devices that tracks all their trips, whether they are by car, bike, walk or transit. This information is typically monitored for one or two days and then compared to the travel diary that the respondent completed as part of the original core sample. The extra number of trips recorded shows the level of trip under-reporting. The New York survey found that almost all its under-reported trips were non-motorized, with an under-reporting rate of 18%.

3.2.2 Exclusive non-motorized travel surveys

In view of the underreporting problem associated with the conventional travel and census surveys, a few surveys have been specifically designed to collect information about users of walk and bicycle modes and their characteristics. For example, Antonakos (1994) targeted cyclists at four recreational bicycle tours in Michigan and studied their environmental and travel preferences. Since the universe of the survey excluded cyclists who bicycle only for utilitarian transportation and non-cyclists, the findings from this study may not be generalized (Antonakos, 1994). Another example is the 2002 National Survey of Pedestrian and Bicyclist Attitudes and Behaviors conducted by the U.S. Department of Transportation's National Highway Traffic 9 Safety Administration and the Bureau of Transportation Statistics (2002). The survey collected data on non-motorized travel frequency, nature of trips, reasons for not biking/walking, perception of safety, safety practice, facility availability, community design, safe routes to school, and socio-demographics. Respondents were asked to provide information about their overall non-motorized travel behavior during the past 30 days, with a focus on individual trips made on the most recent day they walked or bicycled (National Highway Traffic Safety Administration, 2002). The data provided a rich source of information to help planning for non-motorized travel.

More recently, the 2013 Utah Travel Study attempted to explicitly collect the pedestrian and bike movements of its household survey respondents by additionally requiring every one of them to complete a Bike/Pedestrian Debrief Survey. Of all adult, 71% reported making at least one walking trip of 10 minutes or more in the prior week, with 21% having made more than 5 trips (Resource Systems Group (RSG), 2013).

3.2.3 Attitudinal Surveys

The planning of non-motorized travel can also benefit from attitudinal survey data. These surveys involve asking hypothetical questions to identify the relative importance people place on environmental and other factors. In the 2013 Utah Travel Study, prevalent attitudes about biking and walking were studied and information about potential barriers was collected through a satellite Bike/Pedestrian Barrier Study that was administered to members of the core sample who volunteered and to members of bike clubs and various neighbourhood groups that were recruited. For instance, 66% of respondents said they agreed that transportation funds should help pay for biking and walking facilities, suggesting a positive attitude for more non-motorized travel. (Resource Systems Group (RSG), 2013)

When this information is coupled with responses to stated preference surveys, policy makers can develop better models for understanding a general population affinity and demand for biking and pedestrian infrastructure. However, as Dill and Carr cautioned, the results of stated preference surveys are "influenced by the wording of the questions and they only reveal what people might do, rather than what they actually do" (Dill & Carr, 2003). Thus, unless carefully designed, the surveys can significantly overestimate the actual response to a bicycle or pedestrian improvement. This is because people are likely to overstate their use of non-motorized modes after potential improvement (Schwartz, et al., 1999).

3.3 Under-reporting at the trip generation stage

In addition to the under-reporting of non-motorized trips from respondents at the survey stage itself, they are also effectively lost further down the 4-step model (Iacono, et al., 2010) due to the following factors:

- Since employment and housing are all measured zonally (with them located at zone centroids), a lot of the intra-zonal trips which tend to be non-motorized are underreported or completely ignored in travel demand modeling.
- Even if we somehow manage to get respondents to perfectly represent non-motorized modes, there are problems associated with modeling the data. This is because the networks used for vehicular modeling are too coarse to represent the route choices used by pedestrians or bicyclists.
- In addition, route choices are also not dependent as much on travel times or congestion (as would be considered in regular logit models for motorized modes). Instead they are more likely to be dependent on experiential and qualitative measures based on aesthetical and environmental factors.

None of the surveys or papers studied specifically dealt with this issue. One obvious solution that allows for a better characterization of these lost trips is using smaller zones to identify potential origins and destinations. This method has been used elsewhere to model non-motorized destination choice, using zones roughly aligned with Census tracts (Eash, 1999). Given the need to change the transport networks used in household survey models in order for this solution to be implemented, this is probably too ambitious for the TTS pilot coming up in 2016.

3.4 Recommendations

- Care must be taken when framing questions that deal with non-motorized travel. Instead of asking "what portion of trips involve only non-motorized travel", ask "what portion of trips involve some non-motorized travel"
- If budgetary constraints allow, follow a similar GPS sub-sample approach in the TTS pilot. Alternatively, assume rate of underreporting to be in 5-15% range based on estimates in other regions.

4 STRATIFIED SAMPLING

4.1 What is stratified sampling?

Stratified sampling involves dividing the parent population into several types or layers and then sampling randomly from each layer, rather than sampling randomly directly from the parent population. The advantage of this method is that it narrows the difference between different types of individuals through classification. This is conducive to extracting representative samples and reducing the sample size. Therefore, compared with random sampling, stratified sampling has relatively remarkable advantages, but the main issue is how to determine the sample sizes for each stratum (Shi, 2015).

Typically, stratification is done at the geographic level, with the study area under consideration divided into distinct geographic zones, which are then each sampled randomly. For instance, in the Vancouver Transportation Panel Survey in 2014, published landlines were stratified by the city's nine transportation zone designations; landlines from each zone were then selected randomly in proportion to the zone population (CH2MHill, 2015).

In the 2007/08 Washington Transportation Survey, the sampling frame was stratified into 30 geographic groups. These strata were composed of aggregations of individual postal carrier routes by jurisdiction and area type within jurisdiction. Next, two area types were defined for this survey: (1) higher-density, mixed-use urban areas, and (2) lower-density areas that are primarily residential. Once stratified by these two considerations, MSG, a third-party vendor, generated a random sample of addresses within each of the strata. This was followed by the survey team calculating the necessary number of addresses to be drawn in each stratum by their proportion in the general population (National Capital Region Transportation Planning Board, 2010). This stratification by geographic zone and area type resulted in better coverage of many demographic groups that were underrepresented in prior surveys. In all but one of the survey strata, 95% percent of the target number of samples were completed and overall, the total number of completed samples exceed the target number of samples by 4%. In particular, persons residing in higher-density mixed use areas without a published landline, including cell-only households, also were sampled at above 95% the target number. (National Capital Region Transportation Planning Board, 2010)

While the other surveys studied also stratified their survey based on geographic zones, no analysis was conducted to determine whether stratifying was beneficial in reducing overall sample size of the survey or whether it was more beneficial in reaching under-represented groups.

4.2 Sample size requirements for stratified sampling:

To determine whether stratification assists in reducing overall sample size for the survey, a case study was conducted in Kunshan City in China. The main urban area was the center of Kunshan City and the city's business service center, which serve as important centres of education, health, culture, finance and administration. The total area is approximately 6.1 square kilometers, with a population of approximately 134 thousand. The residential areas in the main urban area of Kunshan City were classified into three categories: (1) newly developed areas (2) residential buildings built from 20 to 30 years ago and (3) one-story houses constituting old neighborhood-type residential areas. (Shi, 2015)

The sample size for each category was mainly decided by the following: the degree of variation of the survey objects; requirements and the allowable size of error, that is, accuracy requirements; the required confidence coefficient, which, in general, was taken as 95%; the population; and the sampling method. For a mathematical treatment of sample size calculation, refer to "Study on a Stratified Sampling Investigation Method for Resident Travel and the Sampling Rate" by Fei Shi. To get a representative sample, the sampling rates for each of the 3 residential areas were found to be 5.19%, 6.66% and 5.65%, compared to a baseline non-stratified sampling rate of 6.24% for the entire city. (Shi, 2015)

In the Washington survey, the sample size was mainly reduced by isolating hard-to-reach groups before the survey began and then oversampling their strata to cancel the effects of low response rates (National Capital Region Transportation Planning Board, 2010). The latter would have led to resampling and resurveying the entire sample if a stratified approach had not been taken. In California, a similar selective oversampling strategy was implemented where (1) addresses from the census tracts with high concentrations of hard-to-reach groups were oversampled, and (2) these address-based samples were supplemented with 'targeted' listed residential samples. For example, Hispanic households were historically identified as a hard-to-reach group. For the survey, NuStats - the survey group, identified census tracts with a high concentration of this hard-to-reach household type based on Hispanic household, person age and household size data from the 2010 Census. (California Household Travel Survey, 2013)

However, the Vancouver survey report did warn against over stratifying and excessively limiting the sample size. The concern was that this would not produce statistically significant O-D matrices for each traffic zone. In 27 of the 121 O-D pairs of traffic zones analyzed in the 2014 survey, the trip matrices indeed produced statistically insignificant results. (CH2MHill, 2015)

4.3 Strata Size Calculation

As mentioned above, one of the first and most crucial steps in stratified sampling is to determine how to divide the population into different strata. Most large-scale surveys simply demarcate the study area into distinct geographical zones and stratify based on these zones. Depending on the individual needs of the survey, other respondent characteristics are then used to target hard-to-reach groups. Once the strata are determined, strata sizes are determined simply by the proportion of each stratum within the general population. The harder-to-reach groups may be oversampled based on how under-sampled they were historically due to low response rates. This approach has been used by the Vancouver, Washington, New York and California household travel surveys.

In addition, Kim and Mahmassani suggested 3 theoretical methods to determine strata sizes (Kim & Mahmassani, 2014):

- Optimal allocation for mean - The total sample size needs to be distributed across each individual stratum in proportion to the product of stratum probability and stratum standard deviation.
- Proportional allocation – allocation based on stratum weights, i.e. stratum population.
- Uniform allocation – each stratum gets the same sample size

The travel information from each stratum are then simulated using traffic simulation models to obtain travel time distributions that reflect a wide range of potential variations in travel time. These are captured through multiple input scenarios, and provide a basis for extracting various reliability performance metrics. The study findings were as follows (Kim & Mahmassani, 2014):

- Optimal allocation for mean was found to best predict travel time behaviour.
- Proportional allocation produced significantly lower estimation precision than other tested methods in all test cases.

- Uniform allocation had a good performance in the experiment, but the researchers concluded that its performance is expected to highly depend on specific characteristics of a given data set.

This is counter-intuitive, as one would presume that strata that are proportionally allocated are the truest indicators of the actual population and their behaviour. However, determining strata sizes by optimal allocation for the mean remains a theoretical idea and none of the surveys studied utilized this method.

In general, the main advantages of stratified sampling are that parameter estimation of each layer can be obtained. The sample for stratified sampling is more representative than that for random sampling, thereby improving the accuracy of the parameter estimation. It also greatly reduces the investigation sample size compared with random sampling. Both random sampling and stratified sampling require a certain workload of pre-investigation beforehand to obtain the variance and to further determine the sampling rate. (Shi, 2015)

4.4 Stratified sampling and accurate O-D matrices

Given that the purpose of household surveys is to obtain representative O-D matrices for each traffic zone, theoretical experiments have been conducted to determine how large a sample size should be to provide accurate O-D information in a region. In Cools et. al, a Monte Carlo experiment was set up to estimate the precision of the O-D matrices given different sampling rates. For each of the different sampling rates, 2000 random stratified samples were drawn. To ensure that the persons in the samples were geographically distributed, the sample was stratified by geographical area: three nested stratification levels—province, district, and municipality—were taken into account. The sample was proportionately allocated to the strata. (Cools, et al., 2014)

It was found that accurate O-D matrices at the provincial level could only be derived when half the population is queried, i.e. sample size needs to be quite large (Cools, et al., 2014). Unless stratified samples are used to target city municipalities or a specific small population, stratified sampling is not a good strategy for widespread transportation demand modeling.

4.5 Highlights and Recommendations:

- Stratification is typically done geographically.
- Stratification in Washington survey resulted in better coverage of under-represented groups.
- A case study to determine whether stratification reduces overall sample size was conducted in Kunshan City in China. Stratification for the 3 regional strata was found to be beneficial as it led to sampling rates of 5.19%, 6.66% and 5.65%, compared to a baseline non-stratified sampling rate of 6.24% for entire city.
- In Washington and California, a selective oversampling strategy for underrepresented groups was implemented after stratification to counter the effect of low response rates.
    - Recommendation: In the TTS pilot, by initially identifying hard-to-reach strata and oversampling them, time and money can be saved by avoiding resampling and resurveying of entire sample if hard-to-reach groups remained underrepresented.
- Strata sizes are typically determined by their proportion in the general population. As discussed above, hard-to-reach groups may be oversampled.
- In addition, there are 3 theoretical methods to determine strata sizes:
    - Optimal allocation for mean – size distributed in proportion to product of stratum probability and standard deviation.
    - Proportional allocation – allocation based on stratum population, i.e the default approach

    - Uniform allocation – all strata have same size
- Optimal allocation for mean found to best predict behaviour. However, in practice, no survey has utilized this method.
    - Recommendation: Conduct a small-scale pilot using optimal allocation for mean instead of proportional allocation to check if groups are best represented that way.
- Stratified samples are not valid for provincial level surveys, however are a good strategy for small populations or city municipalities.

5 PROXY/NON-RESPONSE BIAS

The phenomenon of underreporting of trips by proxy respondents, who are asked to answer for all members of their household, is well documented. A Federal Highway Administration report from 1997 concluded that proxy respondents reported, on average, about 25 percent fewer trips per travel day, and about 20 percent fewer miles traveled and driven than persons responding for themselves (Zimowski, et al., 1997). Proxy reports were suggested only:

- For ascertaining basic demographic information for members of the household
- If the proxy accompanied the actual respondent on the trip or activity

Findings from the 2001 National Household Travel Survey in the US suggested that proxy reports about activities were the least accurate of the measures they examined. Self-reporting persons indicate taking more daily, long distance walk and bike trips, and men and non-drivers were twice as likely to have a proxy response (US Department of Transportation, 2004). In spite of the shortcomings of proxy responses, they have continued to have a presence in major travel surveys, because elimination of proxy reports have been found to have an adverse impact on response rates.

5.1 Proxy bias explained by cognitive effects

To delve deeper, research has also been conducted to study cognitive procedures for correcting proxy-response biases in surveys. In his paper titled *Cognitive procedures for correcting proxy-response biases,* Todorov provides a psychology and statistics oriented methodology to estimate non-response bias, and correct it based on contextual information about knowledge imbalance between respondent and the person who is being proxied. While not carried out as a travel survey (the survey determined proxy knowledge of disabilities suffered by family and friends), the study had some interesting findings. The study concluded that proxy-reports are systematically biased. When respondents are asked to report about other people but do not have sufficient information, they appear to rely on inferences grounded in lay theories about the domain of questions. In the case of disabilities, respondents rely on theories about how disabilities are related to each other. This would lead to over-reporting of disabilities seemingly related to a previously reported disability, and to under-reporting of disabilities seemingly unrelated to the previously reported disability. (Todorov, 2003)

Translated within the context of a household travel survey, travel modes that have been previously reported (for instance use of automobiles or transit for commuting) will dominate the proxy respondents' perception of the trips undertaken by the person being proxied. This exacerbates the issue of under-reporting of non-motorized trips. As these trips are most unrelated to automobile and transit usage for commuting, proxy respondents are generally least aware of them and thus underreport it.

5.2 Countering Proxy-Bias

The most popular method to counter proxy bias is the call-back, where survey interviewers call the household a second or third time if a particular respondent in the household was initially missed. With this approach, there are multiple opportunities to reach every member of the household. For instance, in the California Household Travel Survey, interviewers were required to make a minimum of three call attempts within a seven-day period (California Household Travel Survey, 2013). Households with missing adult information were coded as proxy partials, and follow up calls were made by the same interviewer when possible to maintain rapport and continuity with the household. At the beginning of the fourth day after the assigned travel day, if no contact had been made, the household was released for completion by proxy. This usually meant having the reference person report from memory the activities of the missing adult. In those instances, when the missing travel information could no longer be obtained, the household was technically unresolved and it was coded as a partially completed interview or a partial refusal.

A similar approach was utilized in New York. Proxy person reports were accepted only for children age 16 or under. For adults, at least 3 attempts at contact were required before proxy reporting was permitted (New York Metropolitan Transportation Council , 2014). Finally, in Washington, a call-back policy was implemented for the first 3 days of the survey, after which proxy reporting was permitted (National Capital Region Transportation Planning Board, 2010).

The call-back approach does have some key drawbacks, namely high cost and extended time requirements for repeat visits or calls necessary to obtain information directly from each respondent. In many cases, proxy reporting is allowed simply to avoid these issues (Statistics Canada, 1998). As such, a relevant solution to counter this proxy bias could be by developing a satellite survey that asks all members of the household to keep a travel diary for an entire week. This information can then be compared to data coming from the proxy respondent to determine the rate of underreporting of trips due to proxy bias. Once this rate of underreporting is known, a corrective factor can then be applied to all proxy responses in the general core survey. Using this method, surveyors could get a true estimate of the actual number of trips undertaken without having to call each household multiple times. This approach has not been used by any of the various surveys studied for this report. However, given the increasing popularity of core-satellite surveys, it is one that has a potential for application in the future.

5.3 Recommendations

- Develop a satellite survey that asks all members of the household to keep a travel diary for an entire week. This information can then be compared to data coming from the proxy respondent to determine the rate of underreporting of trips due to proxy bias. Once this rate of underreporting is known, a correcting factor can then be applied to all proxy responses in the general core survey. Test this satellite approach in the pilot to determine whether it can accurately gauge proxy underreporting.

6 CORE-SATELLITE SURVEYS

6.1 What is a core-satellite survey?

Core-satellite is a survey paradigm where in addition to an overall "core" household travel survey for the entire population, one or more smaller "satellite" surveys are conducted to gain specific information regarding sub-populations that are either harder to reach, or have specific travel behaviour needs that need special consideration. Satellites have also been used to measure public attitudes towards mounting challenges faced by contemporary urban areas, such as greenhouse gas emissions, economic productivity and safety and security (Transportation Association of Canada, 2015).

Most Canadian urban regions currently are heavily dependent on household-based travel surveys as a primary source of information concerning travel behaviour. These surveys typically use land-line telephone directories as their sampling frame. This approach is becoming increasingly untenable as fewer households have listed land-line telephone connections, and people increasingly use call-screening or subscription to "Do Not Call" lists to avoid taking survey-related calls.

Thus, an urgent need exists to find alternatives to this traditional approach to travel behaviour data collection. At the same time, smart-phone based apps that use either GPS or cellular signal triangulation, transit smart-card data or web-based interview techniques are raising new possibilities for the collection of large amounts of useful data, and Canadian agencies are increasingly experimenting with such technologies. The use of social media and debit/credit card information in addition to the ones mentioned above is an emerging trend; however, they remain underdeveloped and their efficacy in producing representative samples is untested.

Keeping these various data requirements and data sources in mind, a multi-faceted approach to data collection is generally required, reflecting both the complexity of the behaviours being observed (which may not be feasible to capture with a single sample or instrument), and the need to keep response burdens for a particular survey within reasonable levels.

6.2 Integration by content vs Integration by Method

The core-satellite paradigm is an extremely flexible and generalizable approach to meeting different agency needs, whether it be the building of an evidence base in the longer term, or throwing light on "hot button" issues. Although multiple methods are necessary, the main guiding principle is the integration of content rather than method (i.e., defining what content is core, and what can be collected via a satellite process) (Transportation Association of Canada, 2015). Different agencies will use different methods for both their cores and their satellites, depending on their data needs and resources. The focus of core-satellite approaches is the creation of integrated databases; for this, fusion techniques are essential. But of central importance is that fusion, more familiar as a way to merge existing data opportunistically, is undertaken under the core-satellite paradigm by design. These methods can and should evolve over time (with satellite methods generally evolving more quickly and more often than the core), while recognizing the need to maintain data compatibility over time for time-series analysis and consistency in modelling. One approach for maintaining such compatibility is to use both old and new methods during transition periods, so as to be able to test in a controlled way for the impacts of the changes in methods on survey results (Transportation Association of Canada, 2015).

6.3 Examples of core-satellite survey implementations

As has been mentioned previously in this report, one useful implementation of the core-satellite paradigm is in its ability to estimate trip underreporting, caused by difficulty in remembering all trips, proxy bias or under-reporting of non-motorized modes. To this end, the California Household Travel Survey used a GPS satellite survey on a sub-population to accurately collect detailed information about all trips made by this sub-population, regardless of the respondents' answers to survey questions. The idea was to estimate the level of under-reporting in this GPS sub-population and then apply it to the larger non-GPS population (California Household Travel Survey, 2013).

To determine both under-reporting of automobile or transit trips in general, and non-motorized modes, a split design was implemented, with some households receiving in-vehicle GPS devices and other households receiving wearable GPS devices. The GPS devices were used for seven days by the vehicle sample and three days by the wearable sample, with the first day coinciding with the assigned diary/travel day. A portion of the vehicle sample was also specified to receive On-Board Diagnostic (OBD) Engine Sensors to use in tandem with the vehicle GPS devices, to provide additional details about vehicle and engine activity. This info was then used to estimate fuel consumption and emissions levels. (California Household Travel Survey, 2013)

This split technology design allowed for the collection of seven days of highly accurate vehicle-based data with minimal respondent burden, while limiting the burden of carrying wearable GPS devices to a three-day period. A $25 incentive per instrumented vehicle or person was offered to all those recruited, in compensation for successful reporting of travel data, for use of all GPS devices provided, and for return of all devices.

Similar GPS satellite surveys have been undertaken in both the New York and Washington surveys to determine the level of underreporting in the main core survey. In the New York survey, the design also called for the use of Prompted Recall (PR) interviews, wherein a participant was able to view their recorded GPS data while responding to questions about their trips via a web interface. Participants who confirmed their travel via a Computer Assisted Telephone Interview (CATI) were prompted by a CATI operator viewing the participant's GPS trips. The level of underreporting in the survey was calculated to be 18%. The GPS sub-sample showed a mean of 12 daily trips per participant, while the larger non-GPS core sample showed a mean of 9.7 daily trips per participant. (New York Metropolitan Transportation Council , 2014)

In addition, in order to better target the hard-to-reach groups, the California survey used address-based sample that was supplemented with samples drawn from the listed residential frame. This latter frame included listed telephone numbers from working blocks of numbers in the United States, for which the name and address associated with the telephone number were known. The "targeted" Listed Residential sample, as available from the sampling vendor, included low-income listed sample, large-household listed sample, young population sample, and Spanish-surname sample. In conjunction with an oversampling stratified strategy, this sample was used to further strengthen the coverage of hard-to-reach households (California Household Travel Survey, 2013). The advantage of drawing a sample from this frame is its efficiency in conducting the survey effort—being able to directly reach the hard-to-reach households and secure their participation in the survey in a direct and active approach.

In Vancouver, for the core landline survey, the survey group conducted random probability sampling to best reflect the population demographics in the nine transportation zones. However, in the prior-year survey, they found that all existing landline samples in CBD-False Creek, a geographical zone, had been contacted and still the zone was below target in responses. As such, the survey group developed a separate satellite survey based on the address-based sampling frame method to send 2000 postcard invitations with a link to the online survey to residents in the area. However, this measure was not as successful as anticipated, with only 14 diaries completed of the 2000 invitations. (CH2MHill, 2015)

In the Utah Travel Study, no satellite surveys were carried out to determine level of trip under-reporting. However, a separate **College Travel Diary** was used to document college student travel which is often under-represented as the college student is a hard-to-reach group. It was a one-day travel diary administered to students from eight college and universities in Utah which focused on off-campus trips (one or both trip ends are off campus) made on the most recent weekday (Resource Systems Group (RSG), 2013). The College Travel Diary's survey design was otherwise very similar to the main Household Travel Diary.

Moreover, six other satellite surveys were implemented in addition to the core household survey to gather richer data from a single travel survey methodology: (Resource Systems Group (RSG), 2013)

The **Long Distance Survey** was a travel diary to understand the long distance trips (40+ miles) that Utahans make. Long distance travel happens more infrequently but greatly impacts a household's vehicle miles traveled. The survey was administered twice over two different seasons, once as a "debrief survey" in conjunction with the Household Travel Diary, and next to a subset of households who had completed the Household Travel Diary and volunteered to participate in future surveys. In order to capture more infrequent trips, respondents were asked to report their "most recent" long distance trip, which may have been the day before taking the survey or six months prior.

The **Bike/Pedestrian Debrief Survey** was administered in conjunction with the Household Travel Diary, in that each adult who completed it was asked to report their walking and biking habits, behaviors and opinions.

The **Bike/Pedestrian Barriers Survey** was administered to two groups: 1) a subset of households who completed the Household Travel Diary and volunteered to participate in future surveys and 2) members of various organizations (bike clubs, neighborhood groups, etc.) that were recruited. Due to the recruiting and public outreach effort, the Barriers Survey used a "convenience sample" to attract as many survey participants as possible. The questionnaire focused on identifying physical barriers to walking and bicycling. Respondents were asked to report "problem areas" (unsafe intersection, roadway with insufficient infrastructure, etc.) as a way to highlight and rank areas for possible improvement.

The **Attitude Debrief Survey** was administered in conjunction with the Household Travel Diary in that each adult who completed it was asked their opinions on a variety of transportation, economic growth, and land use planning topics

The **Residential Choice Stated Preference Survey** was administered to a subset of households who completed the Household Travel Diary and volunteered to participate in future surveys. The questionnaire asked one adult in the household to describe aspects of their current housing and neighborhood characteristics, as well as what their ideal housing and neighborhood would be. Respondents also answered a series of trade-off questions, which were asked as a way to understand residents' preferences for various housing characteristics.

Finally, a transit survey called the **Dixie OnBoard Survey** asked riders of the SunTran bus system to provide details on their trip, their satisfaction with the service, and some demographic information. It was administered as its own survey during the fall of 2012.

6.4 Highlights and Recommendations:

- Core-satellite is useful in its ability to estimate trip underreporting. California, New York and Washington used GPS sub-samples to estimate trip underreporting. Utah used a satellite bike/pedestrian debrief survey to directly ask respondents to record their non-motorized trips.
    - Recommendation: Based on budgetary constraints, use either of these two approaches to estimate underreporting.
- In order to better target the hard-to-reach groups, the California survey address-based sample was also supplemented with samples drawn from the listed residential frame that included listed telephone numbers. In conjunction with an oversampling stratified strategy, this sample was used to further strengthen the coverage of hard-to-reach households.
    - Recommendation: Given that the major hard-to-reach group in the TTS is the 15-34 age group and apartment dwellers, it will be difficult to obtain a residential frame that includes listed telephone numbers as members of these groups typically use cell-phones. It is recommended that this approach is not followed. Instead, only follow the oversampled stratified strategy utilized by the California Household Travel Survey
- In Vancouver, the RDD landline frame was supplemented by a separate satellite survey based on the address-based sampling frame method used to send online survey link information to below-target respondents.
    - Recommendation: Ideally, an RDD frame is avoided and an address-based sampling frame is utilized from the beginning for the overall core survey.
- Utah Travel Study had a separate College Travel Diary to document student travel behaviour.
    - Recommendation: Collaborate with the 4 major GTA universities to conduct a similar satellite survey. College students are one of the most under-represented groups and contacting them through their universities is the most viable option given their mobility, lack of a landline and the propensity to have cell-phone numbers with area codes distinct from their actual location.
- Utah included 6 other satellite surveys, the Long Distance Survey, Bike/Pedestrian Debrief and Barriers Survey, the Attitude Debrief Survey and a Residential Choice Stated Preference Survey.
    - Recommendation: These are all good options for a satellite, conduct whichever are most necessary at that moment and which are financially viable.

7 PILOT RECOMMENDATIONS

7.1 Joint Sampling Frame (Cell Phones to Augment Land Lines)

- Use Address-based sampling for the TTS pilot – given higher accuracy and quality of the frame. Provide the respondent with multiple options to contact the interviewer (online survey link, landline telephone) and an option to send cell-phone contact information back to the interviewer.
- If going down the RDD route, for overall core survey choose traditional RDD frames. Create a satellite survey of cell-phone only households to target hard-to-reach groups such as the 15-31 age groups.
- If going down the RDD route, utilize a screening approach for the pilot and the main survey as well. Screening is simpler and allows for data integrity as the respondent only gives information once (do not terminate the call if the respondent is also selected on an alternate frame, instead remove the respondent from those other frames after their travel information is collected)
- Allocate cell phone and landline sample sizes based on their proportion in the general population. However, if the cost of a landline and cell phone interview differ a lot, allocate the total sample to the 2 strata based on the optimum allocation method to test its efficacy.

7.2 Non-Motorized Modes

- Care must be taken when framing questions that deal with non-motorized travel. E.g. Instead of asking "what portion of trips involve only non-motorized travel", ask "what portion of trips involve some non-motorized travel"
- If budgetary constraints allow, follow a GPS sub-sample approach similar to that in California, New York and Washington. Alternatively, assume rate of underreporting to be in 5-15% range based on estimates in other regions.

7.3 Stratified Sampling

- In the TTS pilot, by initially identifying hard-to-reach strata and oversampling them, time and money can be saved by avoiding resampling and resurveying of entire sample if hard-to-reach groups remained underrepresented.
- Conduct a small-scale pilot using optimal allocation for mean instead of proportional allocation to check if groups are best represented that way.

7.4 Proxy/Non-Response Bias

- Based on budgetary constraints, either implement the call-back approach, or test the implementation of a satellite survey that asks all members of the household to keep a travel diary for an entire week. This information can then be compared to data coming from the proxy respondent to determine the rate of underreporting of trips due to proxy bias.

7.5 Core-Satellite Surveys

- Based on budgetary constraints, use either a GPS sub-sample satellite or a separate bike/pedestrian non-motorized trips satellite surveys to estimate underreporting.
- Given that the major hard-to-reach group in the TTS is the 15-34 age group and apartment dwellers, it will be difficult to obtain a residential frame that includes listed telephone numbers as members of

these groups typically use cell-phones. It is recommended that the California approach of supplementing the address-based sampling method with listed residential frames that have attached telephone information not be followed. Instead, only follow the oversampled stratified strategy utilized by the California Household Travel Survey.

- Collaborate with the 4 major GTA universities to conduct a similar satellite survey. College students are one of the most under-represented groups and contacting them through their universities is the most viable option given their mobility, lack of a landline and the propensity to have cell-phone numbers with area codes distinct from their actual location.
- Satellite surveys such as the Long Distance Survey, Attitudes Surveys and Residential Choice Stated Preference Survey can all be implemented depending on requirement and financial viability.

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