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UTTRI

ADDRESSING ISSUES IN THE HOUSEHOLD TRAVEL SURVEY SAMPLING FRAME

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Transportation Tomorrow Survey 2.0

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EXECUTIVE SUMMARY

The Transportation Tomorrow Survey (TTS) is the largest and most comprehensive regional household travel survey conducted in Ontario, performed every five years surveying 5% of households in the Greater Golden Horseshoe region. The TTS has been using a landline telephone directory as its sampling frame since 1986, but it has been suffering from bias (under-representation of specific population cohorts). The issue has become more significant over the years because of the drastic decline of households with landlines, and because of the difference between the demographics of households with and without landlines. The goal of the research presented in this report was to provide additional direction towards resolving the long-lasting sampling frame issues of coverage and non-response bias of household surveys, especially for the TTS.

Deficiencies were examined in the landline-based frames experienced in past surveys, both in Canada and worldwide. Varying conclusions were found in the literature regarding the issues in landline telephone frames; however, clearer trends were visible once the demographics of past TTS surveys were compared with the demographics of the Canadian census. A distinct increase in bias was found when comparing the age group representations within the region between the 2006 and 2011 TTS results. The young adult population was severely under-represented in the 2006 survey, and the situation worsened in 2011, where less than a quarter of the census tracts properly represented the young adult population adequately. The senior population, on the contrary, was significantly over-represented, especially in the downtown regions. However, no significant bias was observed with respect to gender.

In order to consider specific frames or combinations of frames to best serve the TTS moving forward, an examination was conducted on these other frames and their availability in the region.

First examined were address-based frames in use in mail surveys. The response rate was a huge concern for many survey researchers; it was found that monetary incentives after the initial contact mail, follow up through the mail, and pre-notification letters increased response rate significantly. Analyzing demographics, older middle classed females with higher education have been found to be more likely to respond to mail surveys. However, there were limited studies targeting the GGH area, and demographics have been noted to vary according to the region. It was found that the coverage for the mail frame within the GGH was complete, and available through Canada Post and Info Canada.

Next investigated were frames used for web-based survey. Email list frames are only viable for satellite surveys because of the inaccessibility of the frame, and lack of existing complete email lists. On the other hand, probability-based web panels were found to have similar demographics to the overall population according to varies studies around the world; however, the demographics of popular Canadian web panels are very similar to landline and mail frames, with lower response rates than their international counterparts.

The increasingly popular approach of mixed-mode surveys and mixed sample frames were then examined. It was discovered that increasing the number of data collection modes does increase response rate; however, this increase did not contribute to reducing non-response error because it does not account for coverage bias. The measurement error existing among different modes also hindered the data quality. The difference was more significant between interviewer-assisted survey modes and self-interviewed survey modes.

A deeper look was taken into cell phone and landline dual frames. The dual frame was found to be an efficient way to increase representation of underrepresented demographics in traditional landline frames (specifically men between the ages of 18 and 34). The inclusion of a cell phone frame would also expand coverage of the original frame to correct the issue of non-response bias. While this frame is widely used in the United States, the lack of an available cell phone frame source and the cost of the frames present challenges for their use in Canada.

Finally, alternative frames were considered that are generally not for household surveys, namely employee and post-secondary school surveys. The success of surveys of this nature in the GGH are presented, including a discussion of the potential costs of conducting surveys via these frames.

Based on the analysis of the various types of sample frames, two possible approaches are introduced for moving forward to address the method for constructing a household frame or the way households are recruited for the TTS. The first is transitioning to a traditional multiple household frame survey with some combination of landline, cellphone and mail lists. The second, based on the examination of the alternative non-household frames, is an inverted sampling method, where individuals are contacted via their place of work or study, or through member organizations. The belief is that reaching respondents through organizations introduces credibility to the survey, and may raise the response rates.

In order to properly evaluate these two approaches, two field tests are proposed for summer 2017. The first test should involve a series of experiments examining the respondent profiles of using mail and dual landline-cell based frames; alternatively, with the 2016 TTS moving towards a mixed-mode survey, that data could be analyzed for the same information. The second test should examine the feasibility of the inverted-sampling approach, by first conducting a survey of businesses to examine their willingness to distribute and promote the TTS to their employees, followed by a secondary TTS-like survey to those employees to test the distribution method.

Overall, while advances have been made in the course of this report towards addressing issues in the sample frame for the TTS, additional work is needed to investigate issues where answers were not found in the literature, or to provide region-specific info about the effectiveness of certain techniques. The following rounds of field tests and further pilots in the TTS 2.0 will work to provide these answers.

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TRANSPORTATION TOMORROW SURVEY 2.0

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1 INTRODUCTION

The Transportation Tomorrow Survey (TTS) is the largest and most comprehensive regional household travel survey conducted in Ontario. It is conducted once every five years by the agencies represented on the Transportation Information Steering Committee (TISC). The survey collects transportation-related information on individuals and households, including trip modes, purposes, origins and destinations. Figure 1 shows the variety of data collected over the past surveys. It sets a common transportation data collection standard across the member agencies within the committees. By the 2011 TTS survey, the survey region covered the entire Greater Golden Horseshoe Area (GGH)[1], contacting over 300,000 households, with approximately 150,000 completed interviews (DMG, 2014).

INFORMATION COLLECTED																				
	Demographic Information												Travel Information							
	Household Characteristics			Person Characteristics									Nature of Trip			Means of Travel				
	Dwelling Unit Type	Number of Persons	Vehicles Available	Age	Gender	Possession of Driver's Licence	Usual Place of Work Location	Usual Place of School Location	Free Parking at Usual Place of Work	Possession of Transit Pass	Occupation Type	Work at Home	Start time	Purpose of Trip	Origin and Destination Points	Travel Mode	Vehicle Occupancy	Used ETR4D7	Detailed Transit Routes	GO Train & Subway Stations used
2011 TTS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2006 TTS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•
2001 TTS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•
1996 TTS	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	
1991 TTS	•	•	•	•	•	•	•	•	•				•	•	•	•			•	
1986 TTS	•	•	•	•	•	•							•	•	•	•			•	

FIGURE 1: INFORMATION COLLECTED FROM 1986 TO 211 TTS (DMG, 2011)

The TTS has been using a landline telephone directory as the sampling frame since 1986, but as with all other household surveys relying on landline sampling frames, the TTS has been suffering from bias (under-representation of specific population cohorts). The issue has become more significant over the years because of the drastic decline of households with landlines, and because of the difference between the demographics of households with and without landlines. According to the TTS 2011 data, males between the ages of 18-32 and post-secondary students are under-represented (Data Management Group, 2011).

This bias has been a concern of researchers and planners, as it raises questions about the accuracy and precision of the survey data. This report focusses on particular issues related to the sample frames of household travel surveys. It is built on the prior work by Pulikanti et al. (2015) on the current state of landline survey methods, which briefly discussed the following subjects:

- Sample frames used by other major, mainly transportation-related, public surveys, including joint cell phone and landline sampling frames.
- Collecting data on non-motorized modes, including satellite GPS subsamples and attitudinal surveys.
- The method of stratified sampling.

[1] Refer to [2] for the complete cities and counties included in the GGH

- Proxy/Non-response bias in landline-based surveys.
- The core-satellite survey structure, and examples of implementations.

Pulikanti et al. (2015) introduced some basic options and new ideas for improving the sampling frame. However, a more thorough investigation and pilot tests were deemed necessary to provide a final recommendation for a feasible and adequate sampling frame for TTS 2.0.

The goal of the research presented in this report was to provide additional direction towards resolving the long-lasting sampling frame issues of coverage and non-response bias of household surveys, especially for the TTS. It should, however, be considered as an intermediate step, with additional research remaining before proper recommendations can be provided. The rest of the report is structured in the following manner. Section 2 discusses the importance of the sampling frame and the deficiencies in the landline frame found by other household surveys. Section 3 presents a case study using the 2011 TTS survey data, specifically investigating non-response and coverage error in landline frames, with a focus on bias in respondent representation, both demographically and geographically. Section 4 looks at the sampling frame, response rate and demographics of mail- and web-based surveys. Section 5 examines the concept of mixed-mode surveys, using a newer method of sample frame construction, and how they have been implemented in various surveys. Section 6 takes a deeper look into cell phone and landline dual frames, elaborating on what was found in the prior 2015 report with more cases and scenarios. Section 7 examines various alternative frames, such as employee surveys and post-secondary school surveys, and the two methods of using these alternative frames to construct a complete sampling frame. In the last section, all sampling frames and methods are summarized and compared. The report concludes with recommendations for potential field tests and possible future directions of study to fill identified gaps.

2 SAMPLING FRAME & CURRENT DEFICIENCIES

In travel survey design and execution one of the most critical aspects is the sample frame. Statistics Canada defines a frame as any list, material or device that delimits, identifies and allows access to the elements of the survey population; in the case of household surveys, the elements are individual households (Statistics Canada, 2015). The quality of the sampling frame directly impacts the cost and quality of any survey (Turner, 2003).

There are generally two types of frames: area frames and list frames. Sampling frames of household surveys are usually composed of both types of frames. Area frames set the boundaries of stratified sampling and define the region where the survey is conducted, while the properties of the list frames are determined by the various sampling techniques. For example, an address list frames contain the address and name of the samples while cell phone list frames include information such as name and phone number. In-person interview and mail surveys both utilize address-based sampling, either using an area frame and going from door-to-door, mailbox to mailbox or using a list of addresses and randomly selecting the interview households. If the list frame is composed of landline numbers, a telephone survey can be conducted and stratified using area frames. When a list frame is not available, random digit dialing is utilized and the sample is stratified using the area code (first 3 digits of the telephone number). Web and email-based surveys require a list frame of the population's email addresses. Sometimes multi-frames have been used to reach respondents in different ways, in the hope of obtaining a higher response rate (Turner, 2003). In order to have a representative sample, the sample selection methods are generally separated into two stages to ensure representation of all geographical areas. The early stages of sample selection are typically drawn from area frames with subdivided geographical units, while the last stage is usually selected from a list frame for detailed contact information (Turner, 2003).

The survey frame should ideally match with the intended survey population, otherwise frame coverage bias is introduced. When the frame does not contain the entire population, there is a high chance for a subgroup to be left out or at least under-represented, causing a skewed result. There are, however, also concerns within complete frames, namely response bias from corresponding sampling techniques and differing response rates between demographics. Certain demographics are easier to be reached by one method than another. For example, web survey respondents are significantly younger than mail respondents (Mackety, 2007). Some sampling techniques also obtain lower response rates than others, which can exacerbate the issues of under-representativeness.

2.1 Landline Frames

This section details how to utilize landline frames in various sampling techniques to achieve lower cost and lower response bias. The TTS and many other household surveys have generally used a landline-based survey method because of its high response rate and coverage rate. While other methods may have a higher response rate, such as in-person interviewing, the corresponding costs are also significantly higher than the cost required for landline surveys. Landline surveys have adapted mainly two sampling frames: lists of landline phone number and random digit dialing (RDD) (Gesis, 2011).

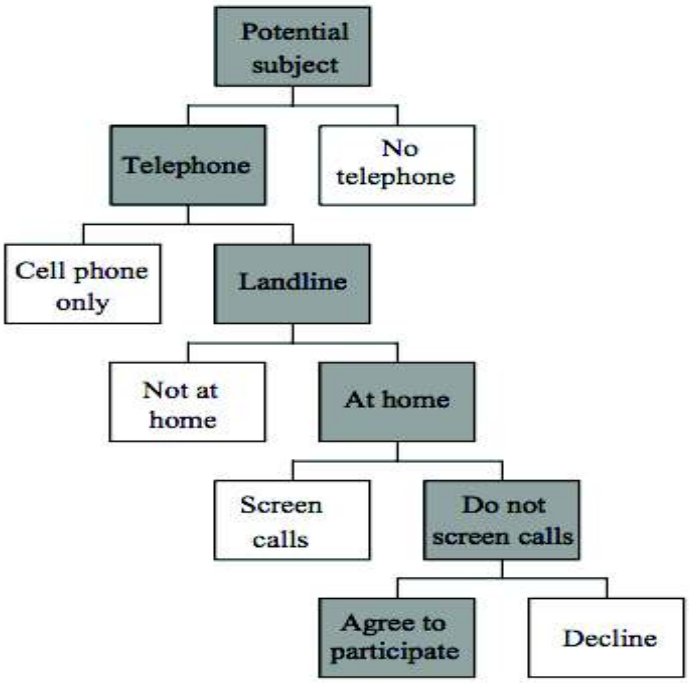

FIGURE 2: STEPS IN THE SELECTION OF PARTICIPANTS IN TELEPHONE SURVEY (KEMPF & REMINGTON, 2007)

Achieving a representative sample of the target population has involved a multiple-step selection process, as illustrated in Figure 2. The participants have often been selected from a listing frame of telephone numbers with name and address (white page). But with the increasing number of unlisted landline phones in recent decades, random digit dialing has become a popular method among researchers (Kempf & Remington, 2007).

Random digit dialing is a traditional sampling method for landline by generating telephone numbers at random. Usually, the set of area codes is fixed to match the designated survey region. As the purchase of the telephone directory is not required, the cost of this frame is essentially zero. However, due to the decline in landline households and the fact telephone numbers are often clustered, most of the generated numbers are invalid (Kempf & Remington, 2007). More calls need to be made to reach the desired response number, which results in a significant rise in the number of calls needed per response and the cost per response.

TABLE 1: RESPONSE RATE FOR DIFFERENT SAMPLING METHOD (MALATEST, 2015)

Phone Based samples used	Contact method	Valid Response Rate
Directory listed landline with address	Letter and phone	43.1%
Directory listed landline with no address	Phone only	27.6%
RDD landline	Phone only	10.8%
Verified cell phone sample	Phone only	13.1%

As an illustrative example, for a survey conducted in the City of St. Albert in 2014, the response rate difference between two methods were examined (Table 1). The response rate obtained from directory-listed

landline numbers was over twice the response rate obtained from the RDD landline numbers. As a result, the additional cost for responses might be more than the amount required for directory purchase (Malatest, 2015).

2.2 Literature Review on Response Bias

The telephone survey method has become problematic since the 1990s because of the noticeable drop in response rate for both RDD and list frames (Curtin, et al., 2005) (Atkeson, 2014). The primary concern is the consequence of low response rate in the accuracy of population and trip estimations. Unfortunately, because of its complexity and costs, only a few rigorously designed studies with actual empirical evidence have been conducted that measure the relationship between non-response and the accuracy of survey data. Two studies, using very different experimental designs, have both found encouraging results, with little evidence for a relationship between response rate to non-response bias in RDD surveys (Keeter, et al., 2000) (Curtin, et al., 2000). Meta-Analysis by Groves (2006) noted that there was no consistent relationship between response rate and nonresponse bias. Holbrook, Pfent and Krosnick (2003) also agreed that RDD telephone with low response rates still generated excellent demographic representativeness, and gave accurate predictions.

Beyond non-response, the declining coverage rate of landline phones due to emerging technology such as mobile phones and the internet has also become a rising concern (Atkeson, 2014). Canada Post reported only 38.5% of the addresses in the Greater Golden Horseshoe (GGH) have an associated landline phone number. The rest are either households without landlines or households on the Do Not Call list (Malatest, 2015). The number of landline households in Canada has decreased from 66% in 2010 to 56% in 2013 at an accelerating rate (Statistics Canada, 2014). The decline in landline usage is more pronounced in younger households where all members are under 35 years-of-age. In 2013, 60% of these households were cell phone-only households that could not be reached by landline, compared to 39% in 2010 and 26% in 2008. These trends are expected to continue as technologies advance; for example, other technologies such as answering machine, caller ID, telemarketing have increased the difficulty for researchers to obtain an ideal response rate (Kempf & Remington, 2007). These serious challenges are threatening the validity of landline-based surveys.

Keeter had two extensive reports about telephone survey published in 1997 and 2006. In Keeter's 2006 report, he expanded on the results of the 1997 study on RDD telephone response rate and demographics. The report was based on two surveys, one "standard" and the second "rigorous", in 2003, utilizing a list-assisted RDD frame to sample 1000 adults. The standard survey was a simple telephone interview over the course of four days, while the rigorous survey had a longer execution time with incentives and follow-up reminders. The response rate of the "standard" survey in 2003 was 25% and the response rate for the "rigorous "survey was 50%. Compared to 1997, both experienced, on average, a 11% decrease because of lower contact and cooperation rates (Keeter, et al., 2006).

However, the demographics composition of a sample of survey respondents were generally very accurate (See Table 2). This was determined via comparison to standard survey demographics with the nation parameters (demographics of surveys that obtained a response rate of 90% or more, U.S. Current Population Survey was used in this case). Nevertheless, some demographic issues were found. Those who identified as Hispanic were substantially under-represented; this was believed to be because the interview was only conducted in English. Younger adults were also under-represented, but the difference was relatively small (28% vs 31%). The biggest mismatch in demographics was in education, where the survey respondents were generally more educated than the benchmark. While 16% of U.S. adults had not completed high school, only 8% of survey respondents failed to do so; also, 34% of survey respondents had a college degree, compared to only 25% in the general population.

TABLE 2: DEMOGRAPHIC AND SOCIAL CHARACTERISTICS (KEETER, ET AL., 2006)

	CPS%	Standard%	Rigorous%	Hardest-to-Reach%[2]
Race				
White	83	82	81	74
Black	11	10	12	15
Ethnicity				
Hispanic	12	7	11	9
Age				
18-24	13	12	9	10
25-34	18	16	17	19
35-44	21	20	18	20
45-54	19	18	20	20
55-64	13	14	15	15
65+	16	18	19	14
Education				
College graduate	25	34	31	31
Some college	23	24	25	26
High school graduate	36	34	33	34
Not a high school graduate	16	8	11	8

Despite a higher response rate, the rigorous survey was found not to have any improvement in reflecting the population demographics. It was not closer in terms of age or income; however, the rigorous survey did reach more of the Hispanic population and was slightly more reflective of the population's education levels. Similarly, as was mentioned in Dimock's 2005 study, counties with higher population density were systematically under-represented in the RDD surveys (Dimock & Samaranayake, 2005). The rigorous protocol did not overcome a common geographic disparity in telephone surveys caused by lower response rates in urban areas. On the other hand, hard-to-reach respondents were more likely to live in high population density areas. Demographically, they were also much closer to the national parameter. However, the number of hard-to-reach respondents (494) was not numerous enough even in this study to offset the bias towards low-density areas (Keeter, et al., 2008).

[2] Hardest to Reach cases had refused the interview at least twice or/and required 21 or more calls to complete

The Sydney Travelling survey (2001) and Denver Region Travel survey (1997) reported non-representative respondent demographics due to coverage error and non-response error. The Denver survey found that the households without landlines were typically very high or very low-income households, households with unemployed persons, older and young single persons, and households with 1 or 4+ members (Denver Regional Council of Governments (DRCOG), 2000). The non-response demographics found by the Sydney survey were similar; the non-respondents were in the 15-49 age group, lived in rented properties, and more often travelled by train or by walking (Ampt & Stopher, 2005).

Carey's study took a step further on researching the non-response bias in 2014 and looked at demographics of telephone surveys nationwide in Australia, specifically for households with and without a listed landline number. The report argued that differences were found both in demographics and lifestyle between the households. People who lived in the unlisted households were generally reported to be younger, lived in a metropolitan area, and resided in lower socioeconomic status areas. They were also more likely to be born outside of Australia and speak a language other than English. However, the survey demographics varied from city to city. For example, a South Australia study argued that the unlisted households were actually more likely to achieve a higher education level, and therefore higher socioeconomic status (Grande & Taylor, 2010). The overall conclusion obtained by this study was that there were different respondent demographics between listed and unlisted households, which implied that the RDD and directory listed landline frames would also have discrepancies in demographics. This study also concluded that although the demographics are generally consistent in different surveys, variation occurs from city to city and differences are even more likely to occur in different countries (Carey, et al., 2014).

To provide a more local context, the most recent study about landline survey demographics and response rate in Canada was from a 2001 epidemiological survey. In the survey, 10613 households were successfully contacted with a 10.8% completion rate. The study, however, reported no significant difference between respondents and non-respondents with respect to gender and mean age which was contradictory to the conclusions of other surveys outside of Canada (Pare, et al., 2001).

Overall, varying conclusions were found in the literature with respect to the issues in landline telephone frames. Since the demographics and response rate varied between countries and time periods, a case study tailored to the GGH is required. The next section presents an analysis of the 2011 TTS demographics to identify the issues occurring in landline sample frame within the GGH.

3 CASE STUDY – TRANSPORTATION TOMORROW 2011 SURVEY

3.1 Current TTS Survey Method

To date, the sampling frame for the Transportation Tomorrow Survey (TTS) has been listed residential telephone numbers, which can be obtained through ASDE, Cornerstone, Info Canada or Canada Post. The most recent survey in 2011 used landline list frames from Cornerstone; with the sample of households being updated monthly with new information obtained from Bell Canada (Data Management Group, 2011). Five percent of the households in Greater Golden Horseshoe Area (GGH) were randomly selected using forward sortation areas (FSA).

The basic survey method consisted of an advance letter mailed to the selected households a week prior to the telephone interview. During the telephone interview, one member of the household was interviewed, and demographic data and travel information were collected for the previous weekday for each member of the household (Data Management Group, 2011). For 2011 survey, the advance letter also provided a special web-access code for the household to provide the option for the respondent to instead complete a web version of the survey.

3.2 Response rate and demographics of the respondents

Using the landline-listing frame over the past decades, TTS has had a maximum response rate of 68.9% in 1996 and a minimum response rate of 48.9% in 2011 (Data Management Group, 2011). Despite the fact that those response rates were still higher than regular mail and web surveys, there has been a significant overall decline in survey response rate. This has also become a common phenomenon in many other telephone surveys.

The 2011 TTS data expansion and validation report examined the difference between respondent's demographics and census's demographics (Data Management Group, 2011). Table 3 presents the age distribution of TTS respondents compared to the census. Compared to the census, there was a clear under-representation of the 18-32 age group, with the census having had nearly twice as many respondents in that age group. The greatest spread of non-representativeness was in Planning District 1 in Toronto (the Toronto Central Area), where a person between 63 and 77 years of age was more than 6 times more likely to have been included in the survey compared to someone in the 18 to 32 age group.

TABLE 3: 2011 TTS AND CENSUS AGE DISTRIBUTION (DATA MANAGEMENT GROUP)

Age Cohort	Proportion of total population	
	TTS Sample	Census Population
0-17	20%	21%
18-32	13%	20%
33-47	20%	22%
48-62	24%	21%
63-77	16%	11%
78+	6.6%	4.8%

Figure 3 and Figure 4 compare the age distribution of unexpanded TTS data for the entire survey area with the 2011 census. The age groups were carefully selected to minimize the effect of respondents rounding their age to the nearest 5-10 years. For the TTS results before 2011, there was some under-representation of the 75+ age group due to the exclusion of institutions (i.e. hospital, nursing homes) from the survey. In the 2006 survey, the 18-27 age range was under-represented by 20% relative to the census; the same differences were observed in the 2011 survey.

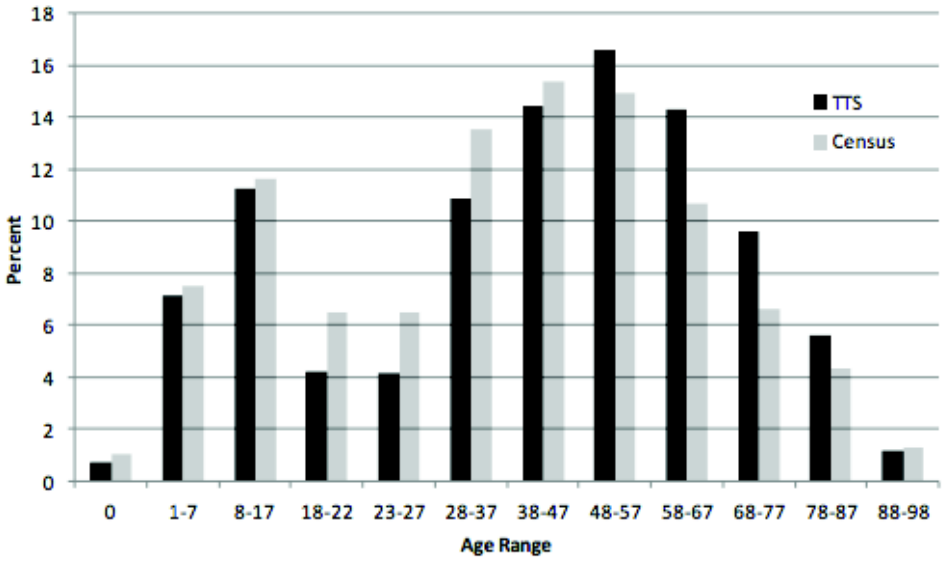

FIGURE 3: FEMALE AGE DISTRIBUTION (DATA MANAGEMENT GROUP)

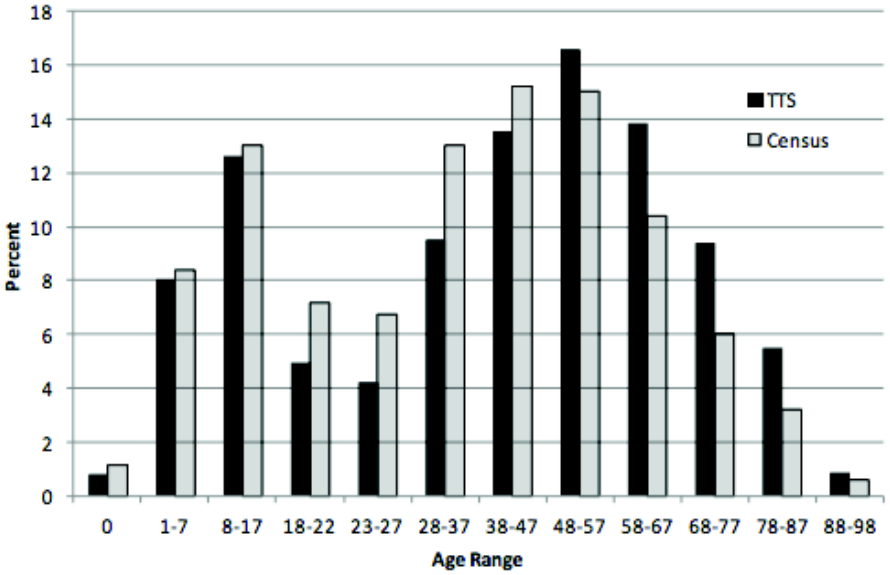

FIGURE 4: MALE AGE DISTRIBUTION (DATA MANAGEMENT GROUP)

While the Data Management Group (2011) report provided an overall comparison for all survey areas, the demographics of respondents in different geographical areas, however, could vary significantly. In order to more precisely examine the geographic deficiency and response bias, microdata obtained from 2011 TTS

were aggregated to the census tract level across two key demographics: age and gender. The aggregated information from TTS was then compared to the census data at the census track level and the percent error ($percent\ error = \frac{TTS\ percent - Census\ percent}{Census\ Percent}$) was graphed in the maps below.

Figure 5 shows the percent error of female respondents in the 2011 TTS survey compared to the census, with the spectrum of representation divided into five sections. The white areas represent a discrepancy within ±10%; yellow and red areas are the regions where female respondents were under-represented and the green areas are female respondents being over-represented. The white spaces observed in Figure 5 implies that the overall female representation was consistent with census data. There was some minor over-representation near Mississauga and in the Hamilton area, but with no obvious trend observed near downtown Toronto. The percent error fluctuated from one census tract to another with no recognizable pattern.

In contrast with the fairly unbiased gender distribution, severe discrepancies were found in the age distributions between the TTS survey and census data (Figures 6-12). To analyze these differences, the sample population was separated into four age groups: children/teens (0-17), young adults (18-34), middle-aged adults (45-64) and seniors (65+). Orange and red regions in the figures are the census tracts where the age group was under-represented, green (light to dark) regions are the census tract areas where the age group was over-represented among survey respondents. The region is lighter when there is less bias, and for regions within ±15% fluctuation[3] of the census distribution, white was used for better representation. The blackened or otherwise shaded areas are the areas with insufficient data.

It is evident from the figures that landline respondents over-represented older adults across the board, especially those above 65 years of age. Likewise, it is clear the group with the largest under-representation was that of young adults. This result was to be expected because contact via landlines can only reach those households where landlines were installed, and younger households have a lower chance of possessing landlines. Furthermore, in landline households, populations who stay at home for a longer period of time, such as retired seniors, are more likely to be reachable by landlines. So, age-cohort-specific discrepancies in representation could also indicate issues of representation in the sample frame, rather than only non-response bias.

Where there is a distinction to be made is that the 0-17 age group was not as uniformly under-represented as the 18-34 group. In certain tracts, there was actually an over-representation of both kids (1-17) and middle-age adults (such as in planning district 1). This also makes sense, as parents with small children (who would fall in the 45-64 age group) were more likely to have a landline at home in order to ensure they could reach call their home. With the 18-34 group however, both children still living with parents and young adults, there is a much higher likelihood that these youths would have their own cell phone, negating the need for a home landline. This is seen in the significant increase in under-representation among TTS respondents.

From a geographical perspective, there were no distinguishing tendencies of certain demographics being over/under-represented in a specific planning district or city; all the non-response biases were distributed fairly uniformly throughout the GGH region. As expected the primary bias is with respect to young adults, who are under-represented in almost the entire GGH region, as observed in Figure 8.

[3] A larger threshold was used to account for the larger inherent percent difference resulting from the multiple age categories compared to the binary gender category

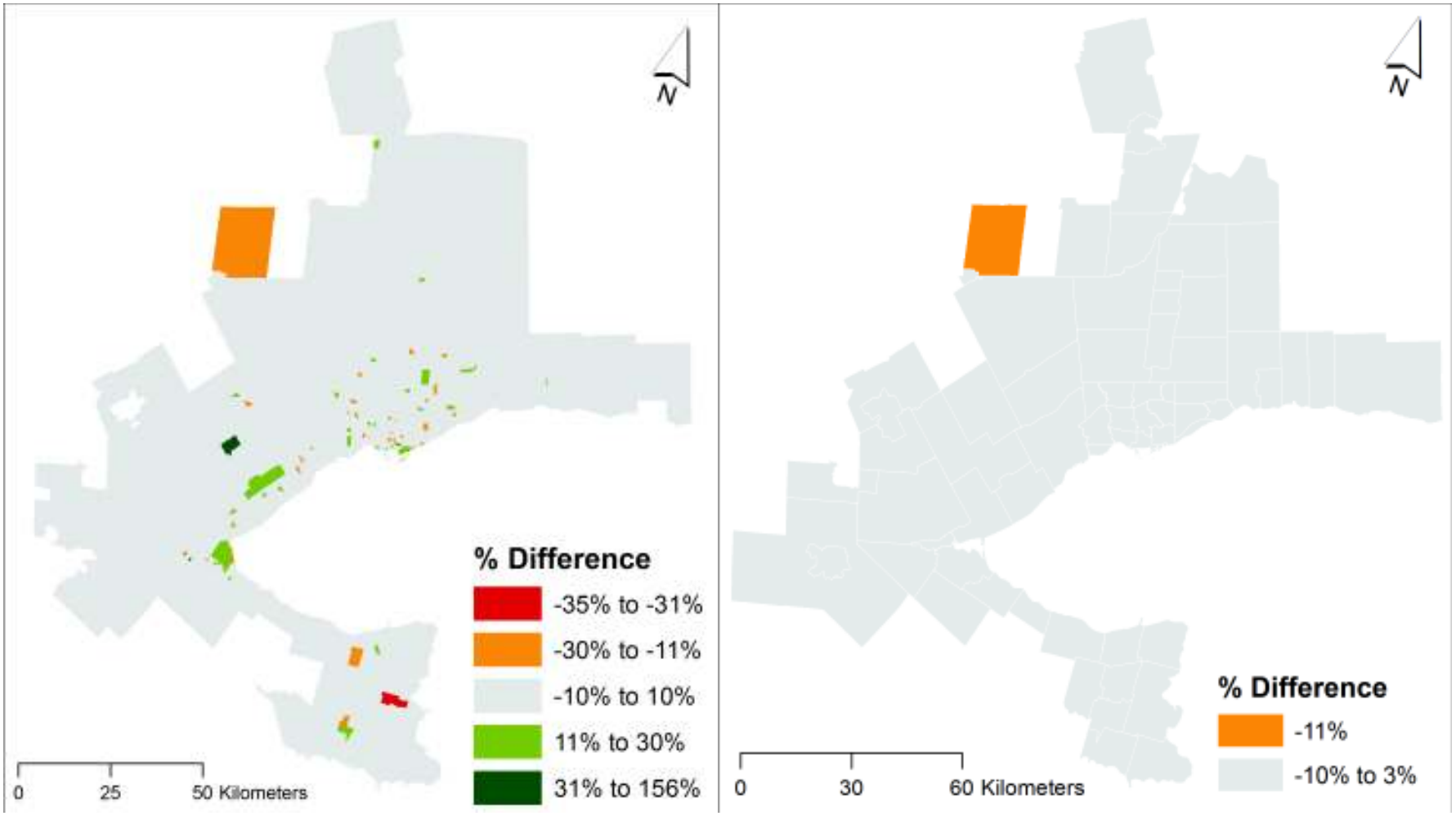

FIGURE 5 2011 FEMALE RESPONDENT DISTRIBUTION VISUALIZED IN ARC MAP

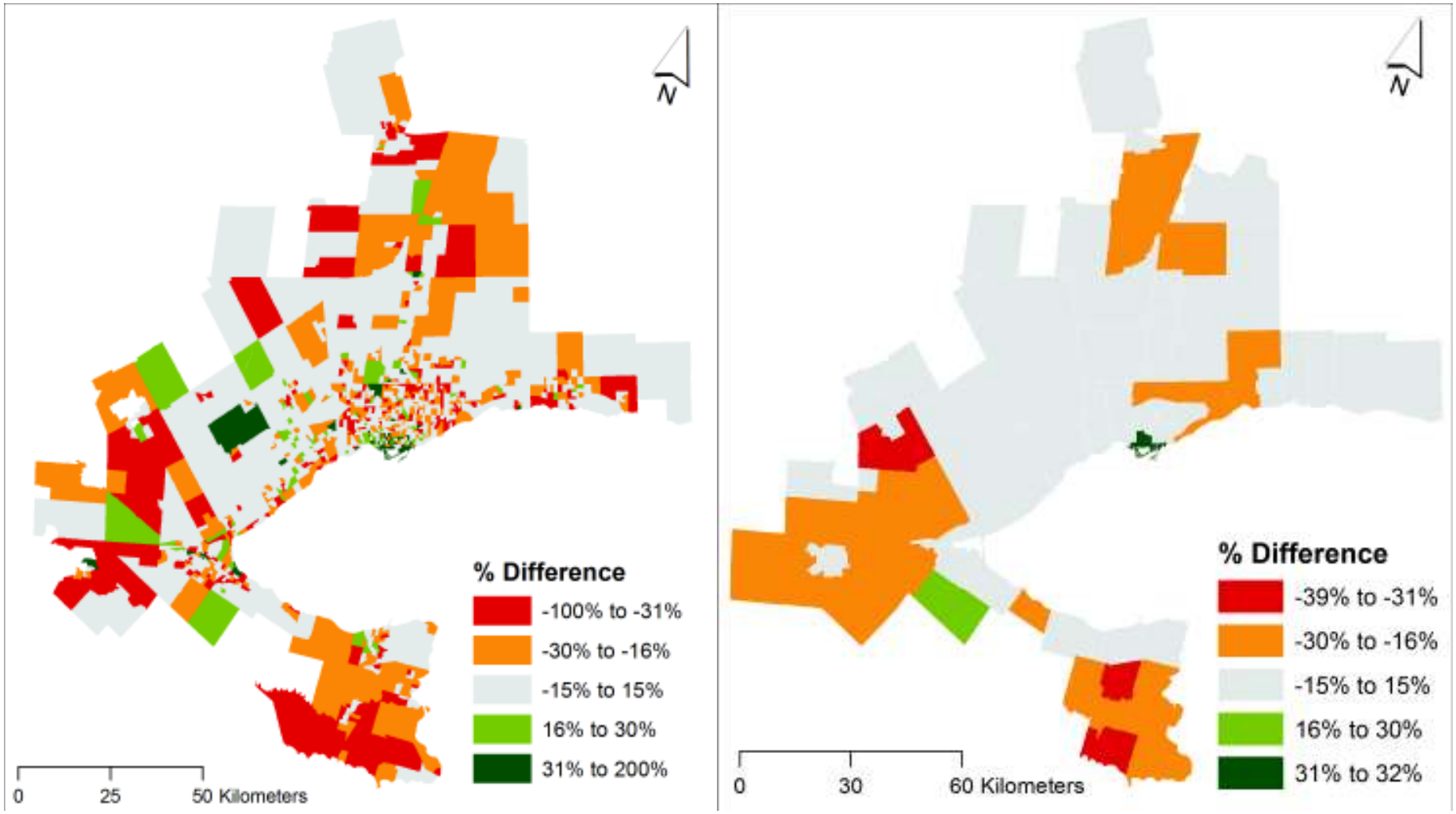

FIGURE 6: 2011 TTS PERCENT ERROR DISTRIBUTION OF CHILDREN (0-17) BY CT AND PD

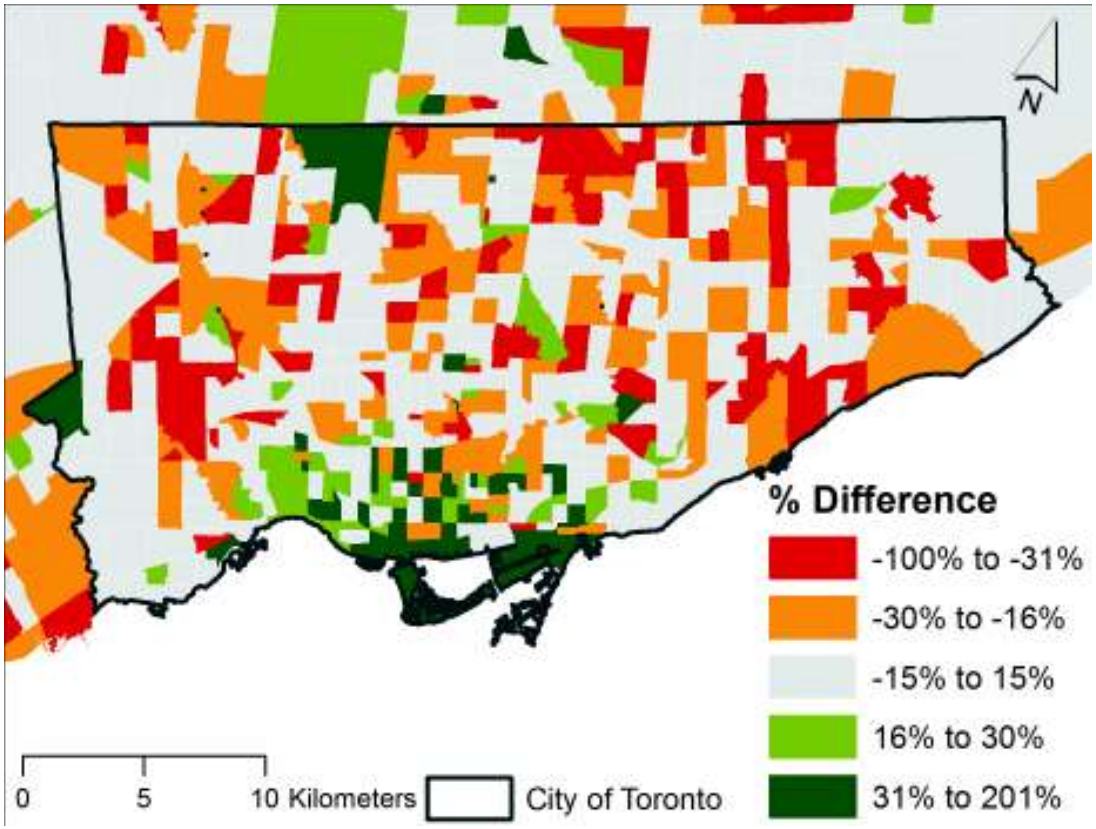

FIGURE 7: 2011 TTS PERCENT ERROR DISTRIBUTION OF CHILDREN (0-17) BY CT IN TORONTO

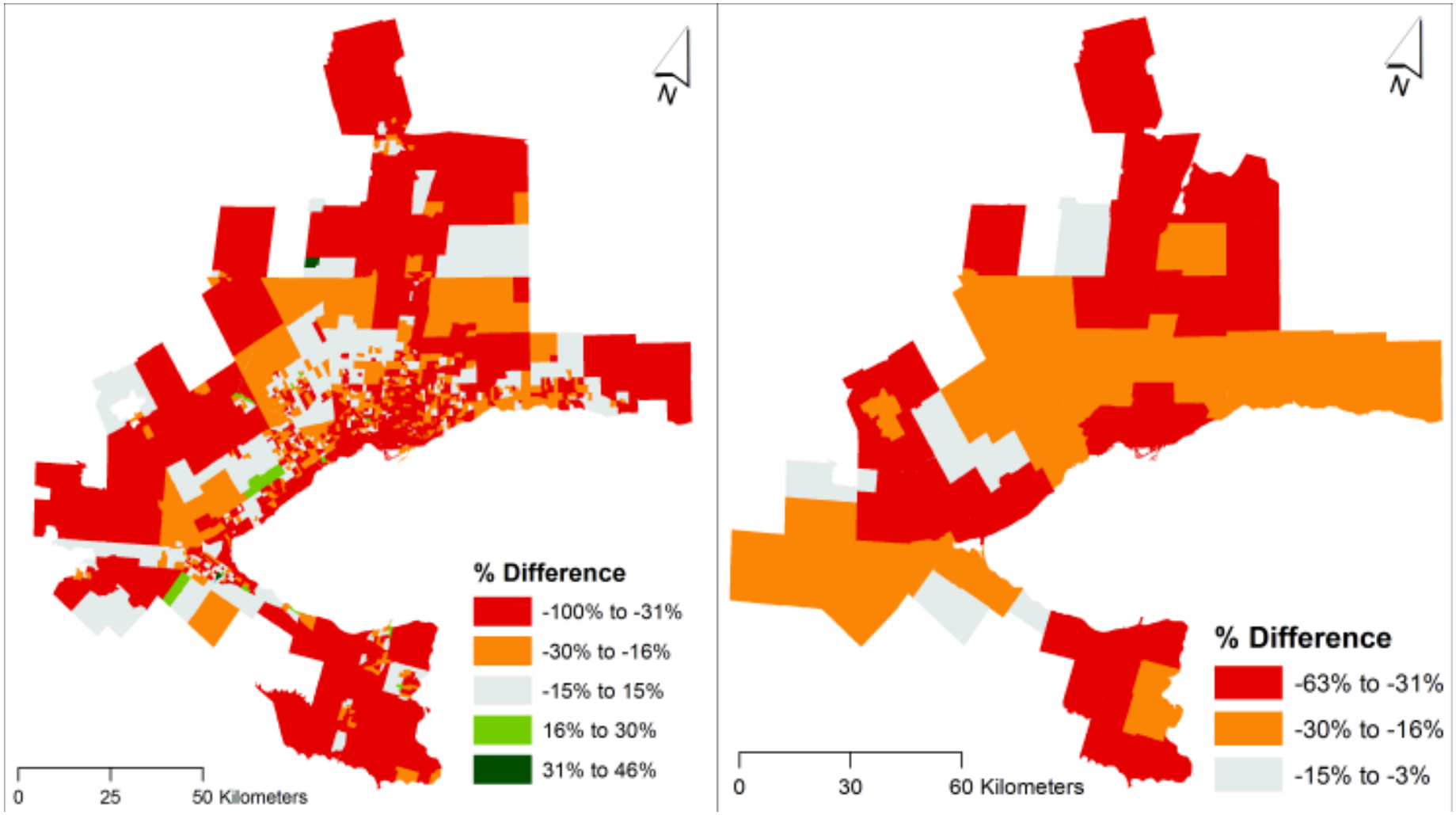

FIGURE 8: 2011 TTS PERCENT ERRORS DISTRIBUTION OF YOUNG ADULTS (18-34) BY CT (LEFT) AND PD (RIGHT)

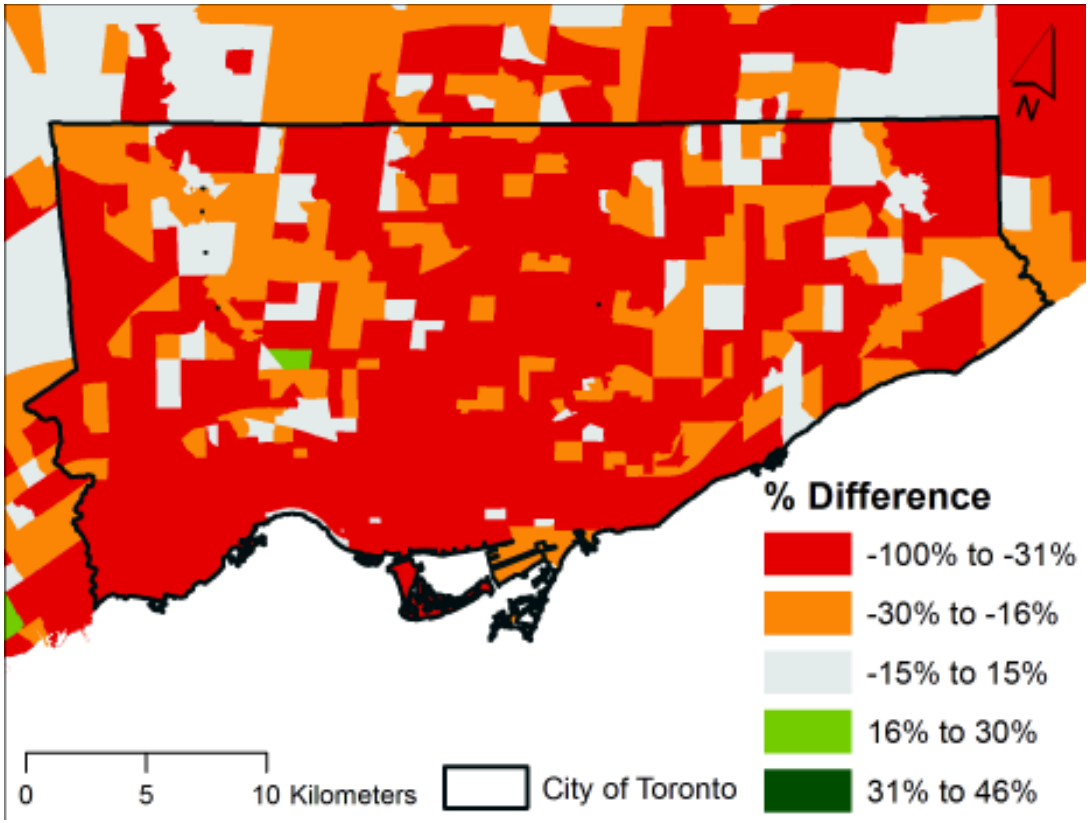

FIGURE 9: 2011 TTS PERCENT ERRORS DISTRIBUTION OF YOUNG ADULTS (18-34) BY CT IN TORONTO

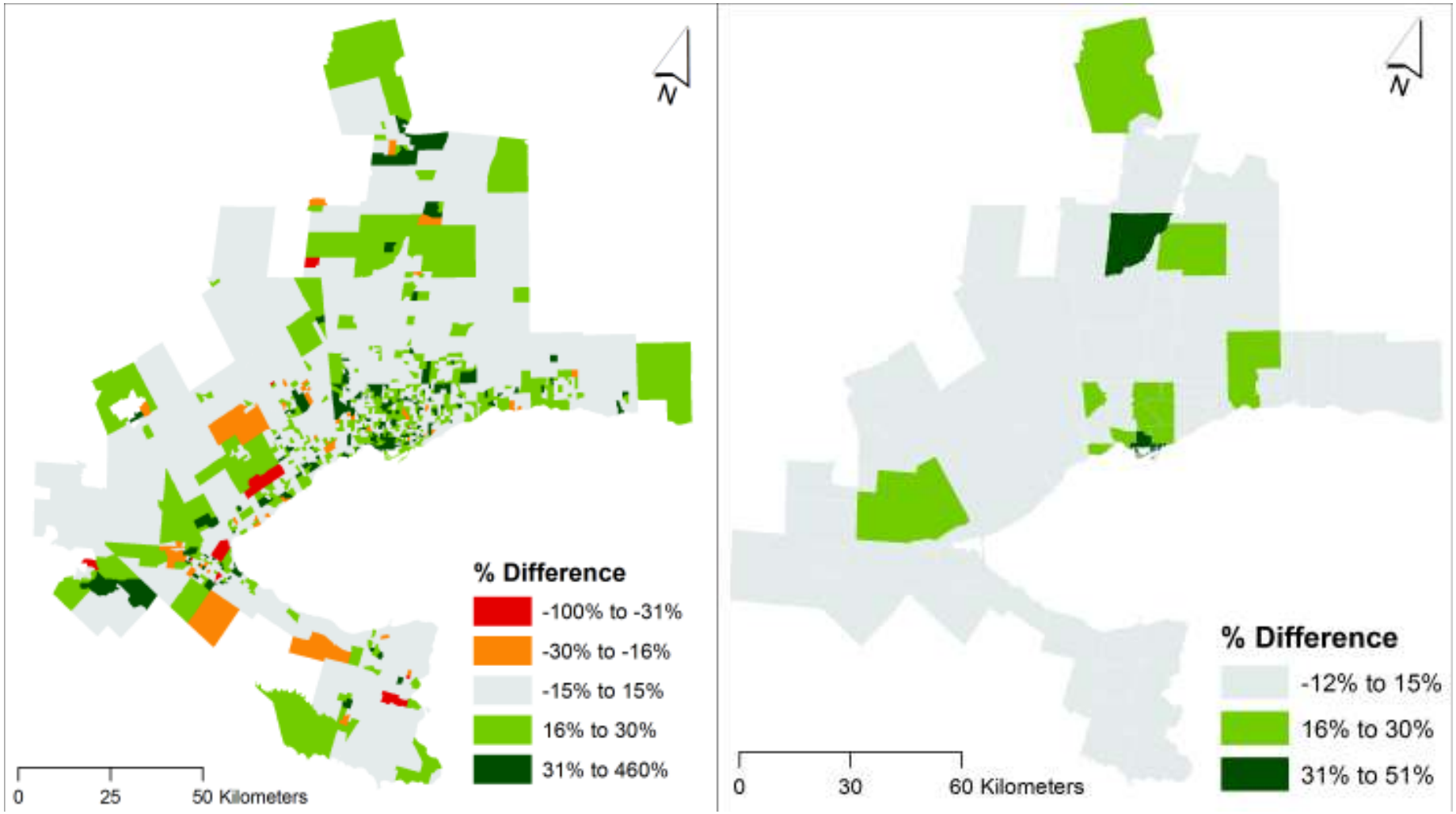

FIGURE 10: 2011 TTS PERCENT ERROR DISTRIBUTION OF MIDDLE-AGED ADULTS (45-64) BY CT (LEFT) AND PD (RIGHT)

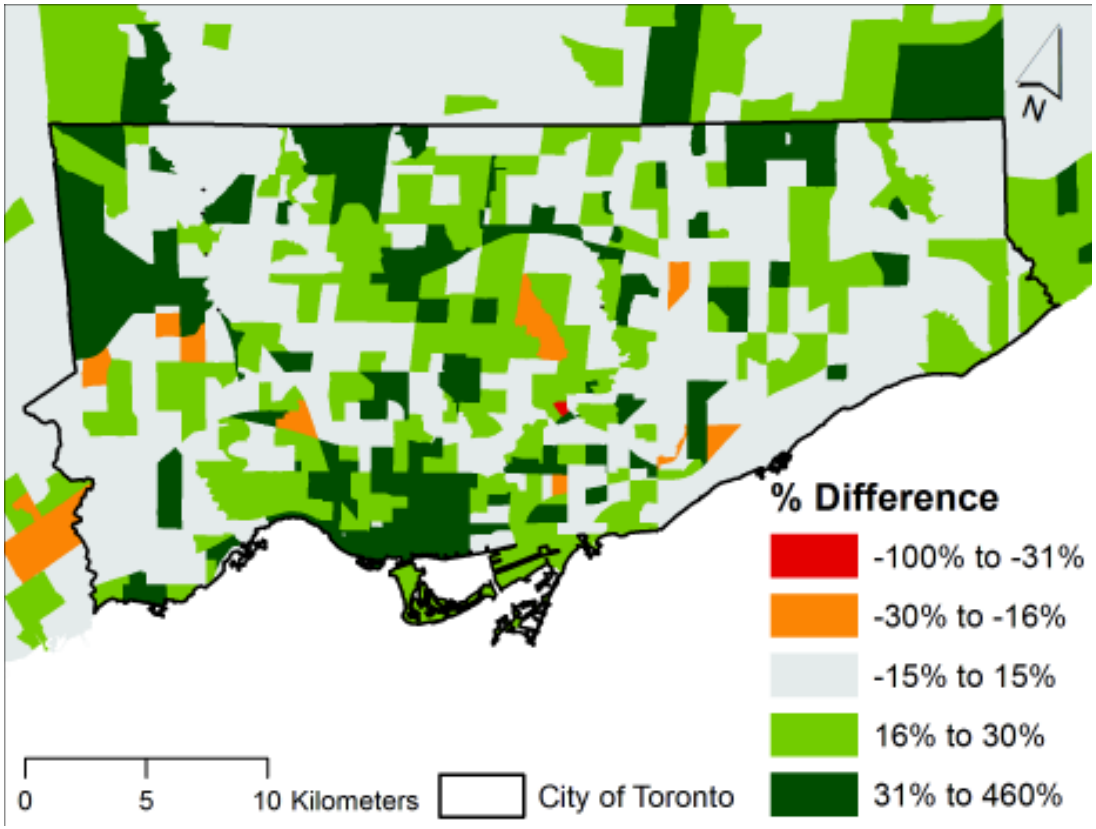

FIGURE 11: 2011 TTS PERCENT ERROR DISTRIBUTION OF MIDDLE-AGED ADULTS (45-64) BY CT IN TORONTO

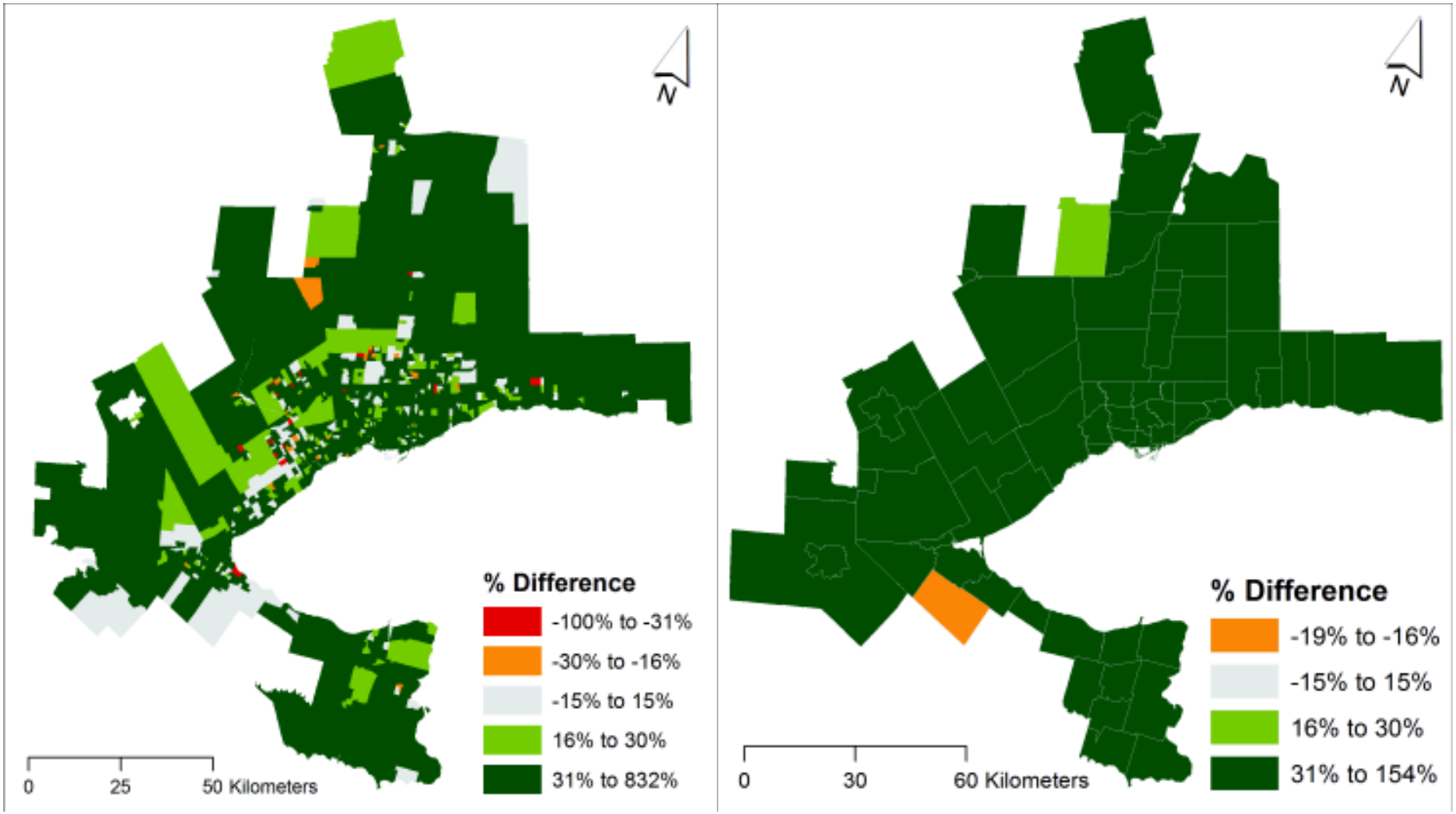

FIGURE 12: 2011 TTS PERCENT ERROR DISTRIBUTION OF SENIORS (65+) BY CT AND PD

In contrast to the consistent under-representation of young adults, senior populations were consistently over-represented in the 2011 TTS survey, especially in the core Toronto area, as shown in Figure 13. Middle age adults were fairly well represented in comparison, with about 75% of census tracts under 15% percent error, and with some over-represented tracts scattered around the denser downtown area. Finally, there was no identified overwhelming geographical bias; the percent error fluctuated between census tracts with no observable trends.

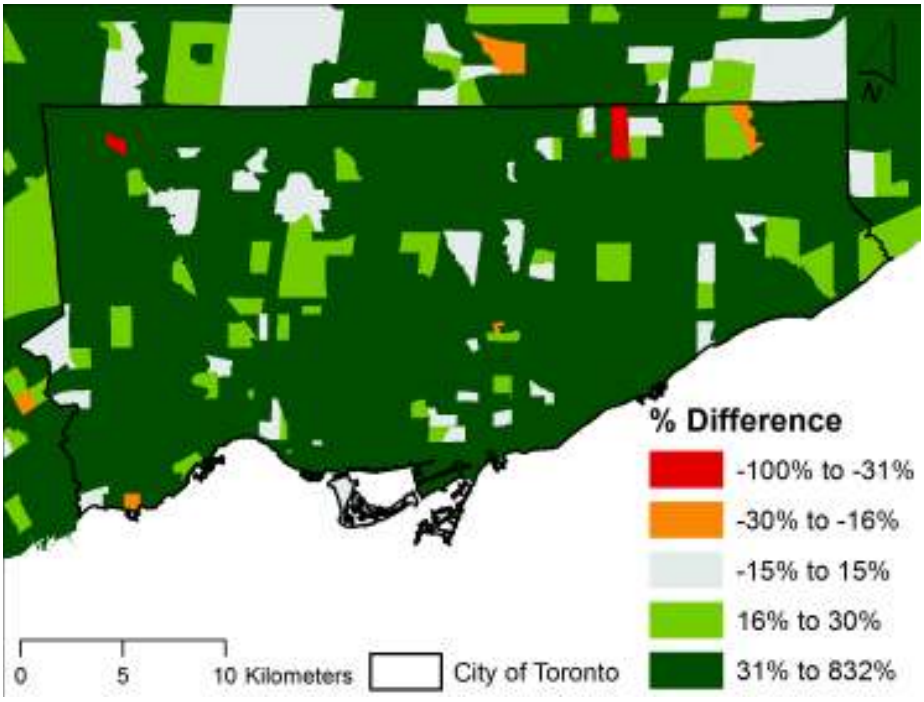

FIGURE 13: 2011 TTS PERCENT ERROR DISTRIBUTION OF SENIORS (65+) BY CT IN TORONTO

Comparing the 2011 TTS percent error distribution with the 2006 percent error distribution (Figures 14-17) for two significantly biased age group (young adults and seniors), it was found that the bias increased with time. Nevertheless, even in 2006, the young adult population was still severely under-represented as seen in Figure 14. Less than a quarter of the map was well-represented (under 15% percent error), while the rest displayed under-representation (shaded red).

In 2011, the situation worsened dramatically; the census tracts where the young adult population was well-represented in 2006 became under-represented because of declining landline usage. The 2006 percent error distribution for seniors differed greatly with the 2011 TTS distribution. In the 2011 map, there was no concentrated area with an over-represented senior population. The number of senior respondents varied with large fluctuations between neighbouring census tracts. Hence, the analysis results were consistent with results observed in the literature; age group bias has been increasing with time, with younger populations dropping in representation.

This case study analysis strongly demonstrates that a landline frame in the GGH region has serious age-related biases. These biases consistently exist across the region. From the past TTS reports, it was found that age groups exhibit significantly different travel behaviour and, hence, any age bias existing in the frame would affect the accuracy of travel behaviour estimates. It is clear that a landline sample frame will not be an adequate choice for future Transportation Tomorrow Surveys.

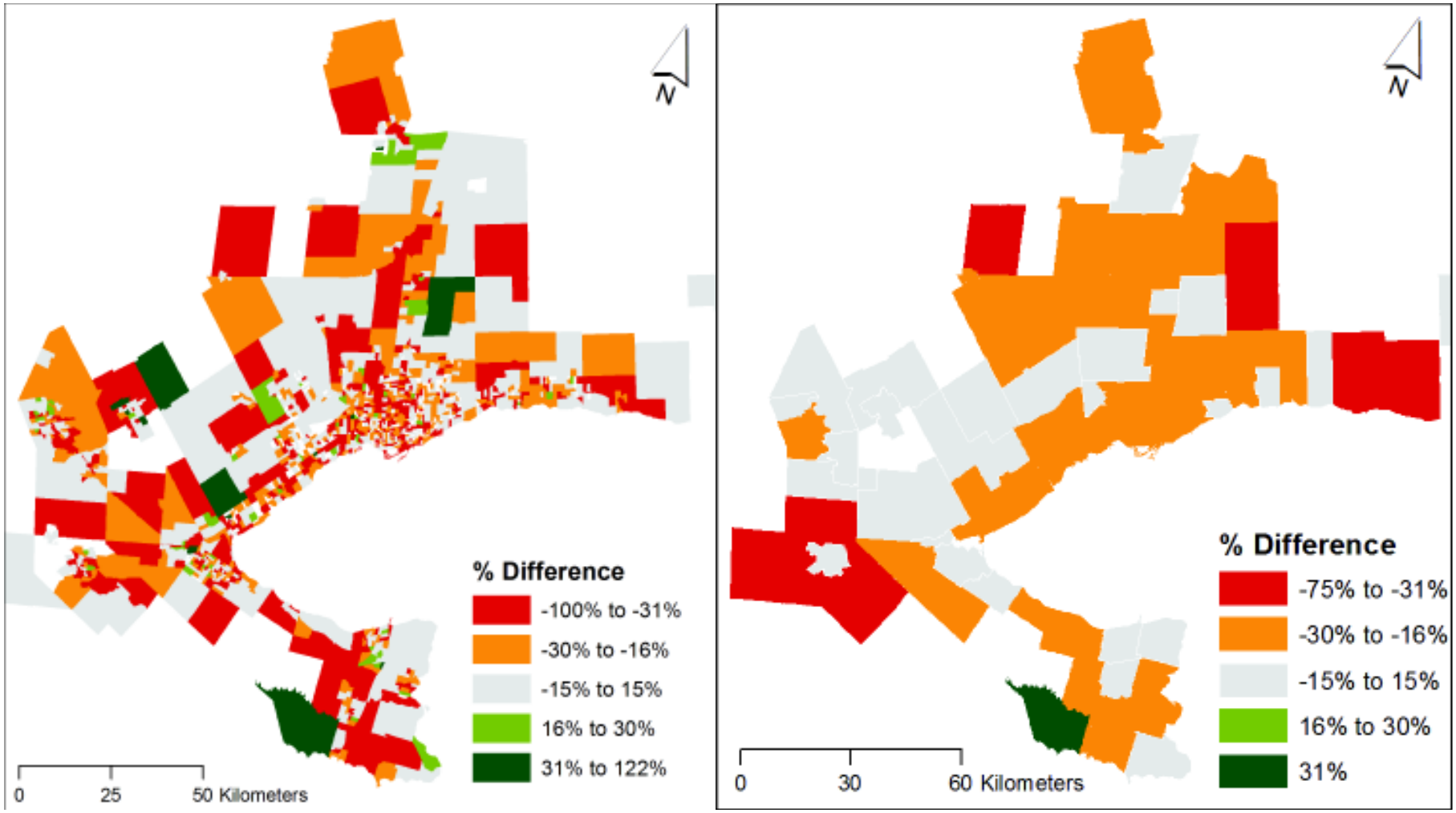

FIGURE 14: 2006 TTS PERCENT ERROR DISTRIBUTION FOR YOUNG ADULTS BY CT AND PD

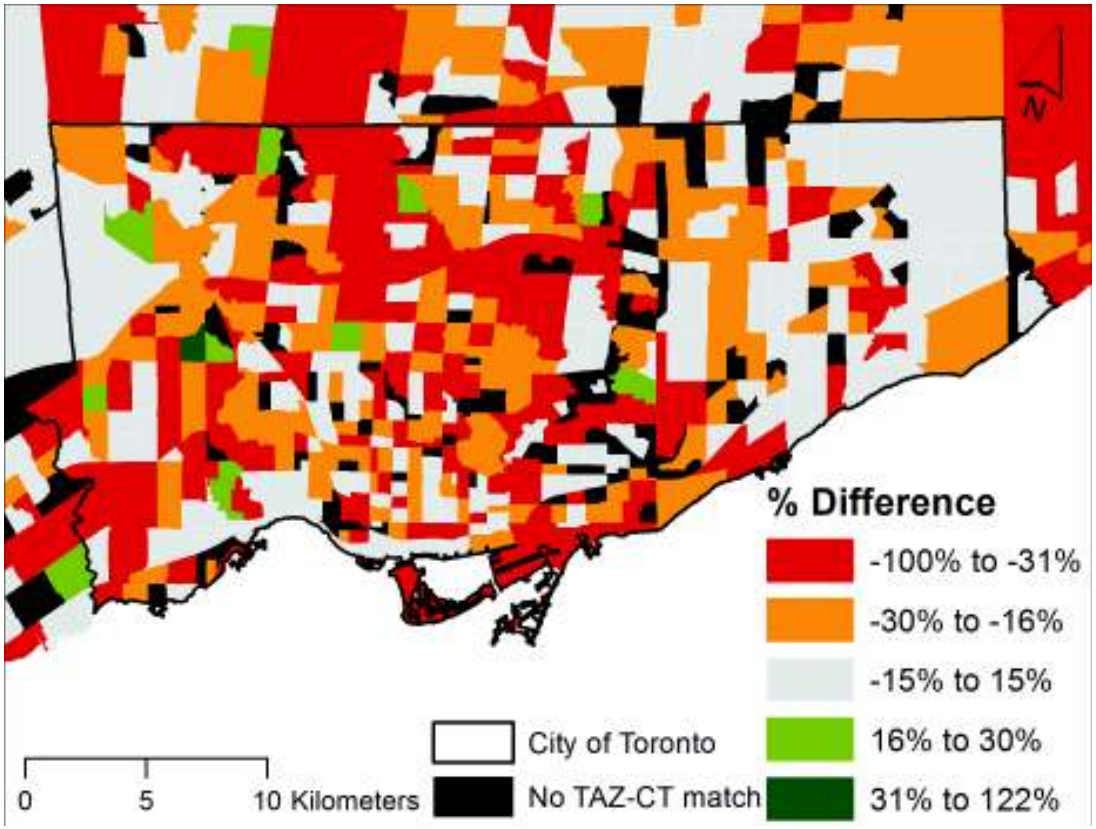

FIGURE 15: 2006 TTS PERCENT ERROR DISTRIBUTION FOR YOUNG ADULTS BY CT IN TORONTO

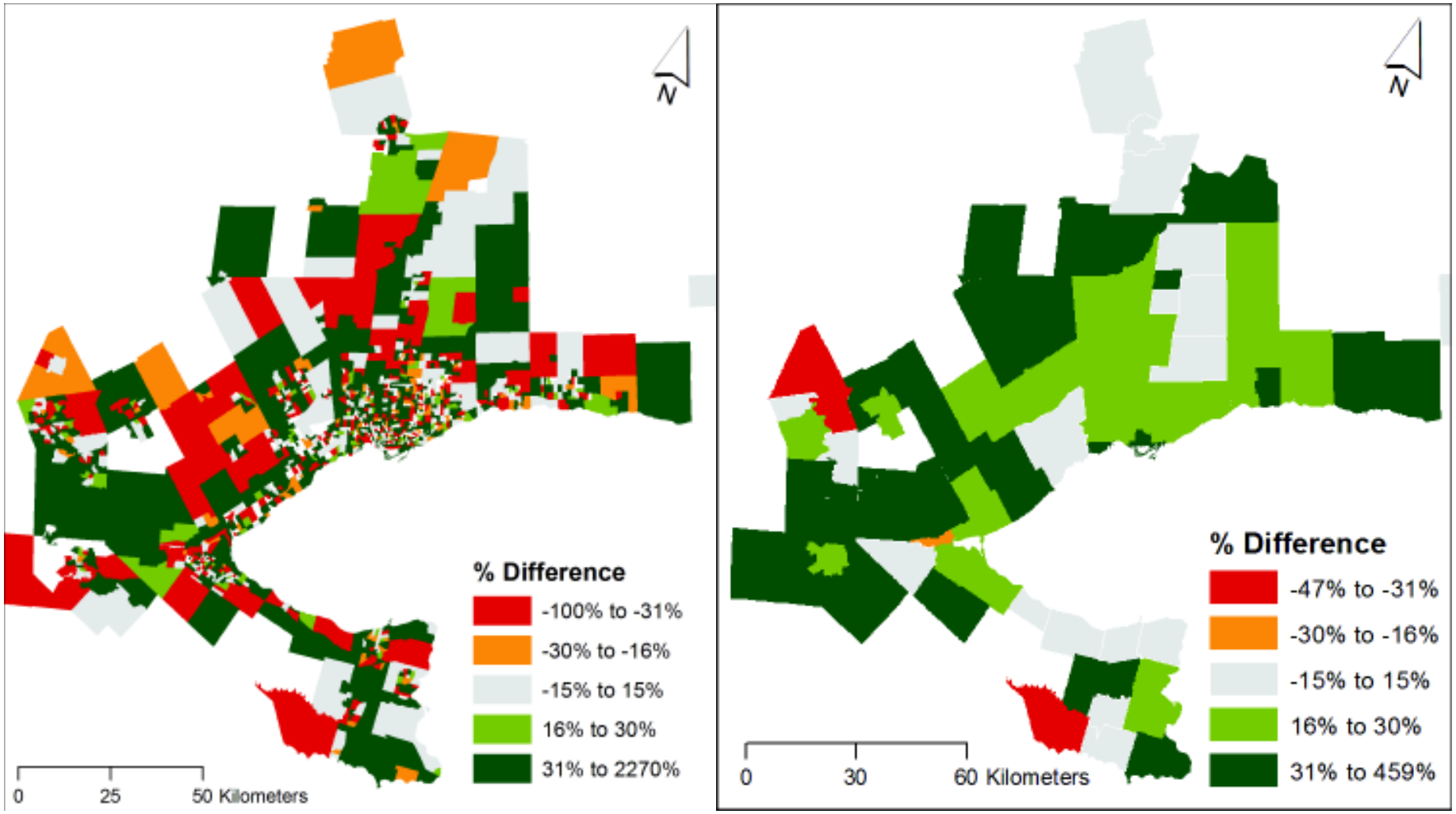

FIGURE 16: 2006 TTS PERCENT ERROR DISTRIBUTION FOR SENIORS BY CT AND PD

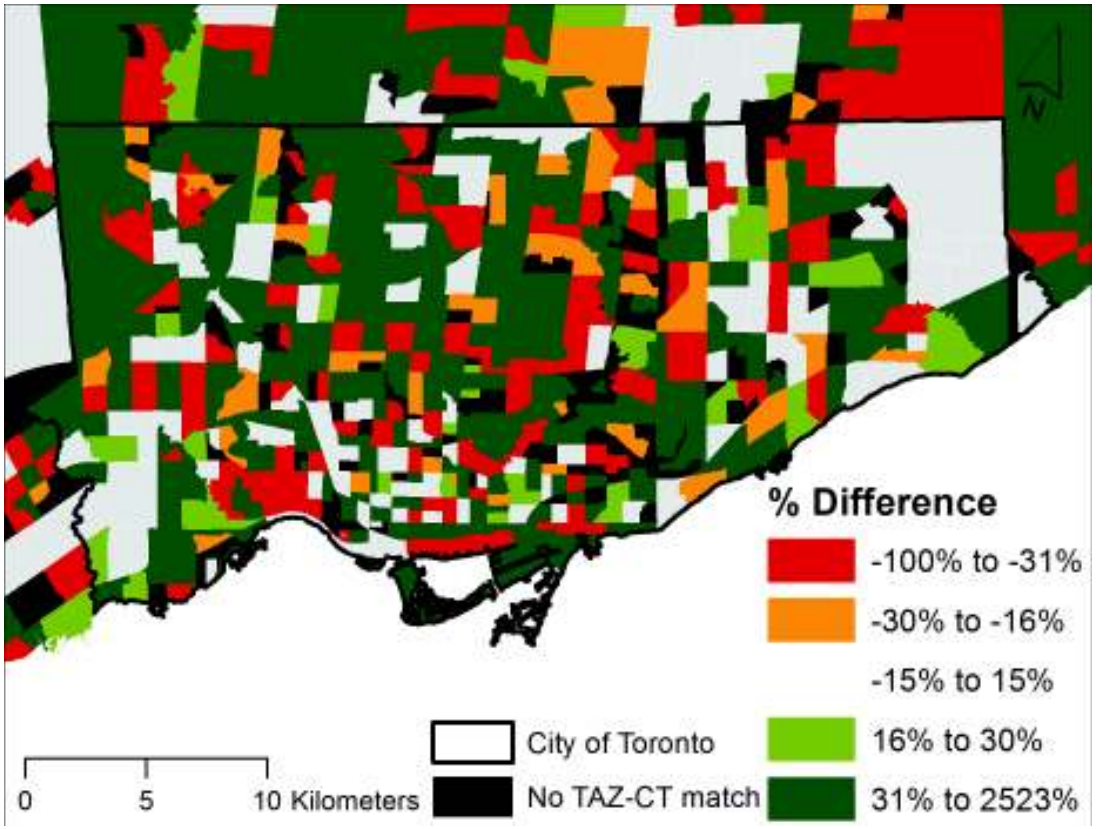

FIGURE 17: 2006 TTS PERCENT ERROR DISTRIBUTION FOR SENIORS BY CT IN TORONTO

4 CONDUCTING MAIL SURVEYS WITH ADDRESS BASED LIST FRAMES

Another common survey method is the mail survey; however, it has been considered inferior to the RDD-based landline survey due to the lack of an adequate sample frame in the past decades. However, due to the increasing incompleteness of landline surveys, coupled with the establishment of the U.S. Postal Service's Delivery Sequence File (DSF), and Canada Posts' increasing coverage of its address lists, mail surveys have recaptured the attention of survey researchers. Contacting households via mail also provides an avenue to implement multiple survey methods, such as the more cost and time-efficient web-based method, which is discussed in later sections.

The completeness of address-based list frames is the biggest advantage of mail surveys because it eliminates one of the two biggest biases in survey data, coverage error of a frame. The U.S. Postal Service's DSF covers around 95 - 97% of the U.S. households, with higher rates in urban areas and lower rates in rural areas (Link, et al., 2008; O'Muircheartaigh, et al., 2007; Steve, et al., 2007; Link, et al., 2005). The Canada Post Canada Complete address list provides a frame with an even higher coverage rate; it has all the addresses of households within Canada (Malatest, 2015). The complete frame allows the respondents from cell phone-only and no telephone households to be included, unlike in landline frames.

Mail surveys are also commonly used because of its low costs and simple implementation (Gregory, 2008). The cost per response has ranged between $5 - $20, depending on the local postal office; this can increase with the implementation of pre-notification letters and follow up mail, but it is still cheaper to conduct than RDD telephone survey (Miller, et al., 2012). The characteristics of address-based frames allow the sample to be stratified regionally with ease. It also is less complicated for future spatial analysis.

4.1 Response Rate

One major reason for survey researchers to choose telephone over a mail survey method is because mail surveys have been known to have low response rates. Although recent studies have suggested that a low response rate does not necessarily yield non-response error or alter survey estimations, the response rate is still generally deemed to be crucial factor in survey quality (Curtin, et al., 2000) (Keeter, et al., 2000). Babbie, in his 2007 research, found that a response rate over 50% is considered adequate, 60% considered a good response rate and over 70% is very good (Babbie, 2007). For example, the U.S. Census Bureau does not accept surveys with less than a 60% response rate (Dillman, et al., 2009a).

The following studies all observed a significant decrease in the mail response rate, intensifying in later years. A meta-analysis in 2008 compared 1607 studies published between 2000 and 2005, from which 490 different studies utilized surveys. It observed an overall decline response rate between 1975 and 2005. The average response rates across all studies dropped from 65% in 1975 linearly to 47% in 1995, before reaching a plateau around 2005 (Baruch & Holtom, 2008). In a separate study, Dillman examined response rate and measurement error of mixed-mode surveys. After discovering a decline in response rate from 70.5% in a 1995 mail control group to 56.2% in 2008, new guidelines were proposed of how to improve response rates (Dillman, et al., 2008). Other meta studies found similar results, with a response rate near 50% around early 2000 (Shih & Fan, 2008; Smyth, et al., 2010). These studies illustrate that the mail response rate has approached the dangerous threshold of an acceptable response rate and a trend pointing to further declines in the future[4].

[4] While these rates are above that of the landline TTS, as the last reference is dated 2010, given the trend, the 2021 response rate may not be better than landline

With the average of a 50% response rate, the mail response rate can go low as 3% in market research and as high as 97% in Canadian censuses (Statistics Canada, 2015). This is due to many factors that can affect the response rate of a mail survey, such as incentives, follow-up reminder, and official authority. The following sections provide a discussion of these methods and identify which have a positive effect on raising the response rate in the most cost-efficient way and, more importantly, if they can also reduce non-response bias.

4.1.1 Incentives and follow-up mails

Incentives are commonly included in surveys to compensate the respondent for the burden of taking the survey (Biner & Kidd, 1994) or the cost of completing the survey. They also represent a symbol of trust or commitment between the respondent and the survey organization (Dillman, et al., 2009a). Numerous studies have found that a financial incentive has consistently increased response rates, particularly in mail surveys (Sudman & Bradburn, 1974) (Ryu, et al., 2006) (James & Bolstien, 1990) (James & Bolstein, 1992) (James & Bolstein, 1992) (Gregory, 2008) (Messer, 2009). Lesser et al in a further examination found that the increase of response rates has usually been around 15-20% (Lesser, et al., 2002).

In the 1990s, James and Bolstein performed their first test with $0.25, $0.50, $1 and $2 incentives, with details shown in Table 4. The response rate reached up to 90% after the fourth wave, and based on the marginal rate of return, a $1 incentive was found to be the most cost effective way to raise response rate after the initial mailing. However, it was also found that incentives increased response rate at a diminishing rate and that the marginal cost was also very high (James & Bolstien, 1990).

TABLE 4: RESPONSE RATES BASED ON MAILING WAVES AND INCENTIVES (JAMES & BOLSTIEN, 1990)

Mailing Number	$0.00 (%)	$0.25 (%)	$0.50 (%)	$1.00 (%)	$2.00 (%)
First Mailing[1]	52.4	62.7	63.1	72.8	77.6
Second Mailing	72.0	74.6	78.0	82.2	88.2
Third Mailing	83.3	82.8	82.7	91.7	94.7
Fourth Mailing	88.1	86.4	86.5	92.9	95.9

James and Bolstein were not satisfied, repeating the experiment in 1992 using larger incentive values, from $1 in cash up to a $50 check. The result was not surprising; higher incentives did not result in a higher response rate. The $50 incentive not only did not increase the response rate, it had the lowest response rate. Accounting for the direct costs of the incentives, labour and supplies per respondent, the $5 incentive was the most effective (James & Bolstein, 1992).

Although the test performed by James and Bolstien was very extensive, as it was outdated, Kansas State University collected additional data from 2000 households in Wichita, Kansas and Los Angeles, California in 2008 (Gregory, 2008). The households were divided into 80 different treatment categories according to survey length, monetary incentives and the use of postcards. Rather than being a payment to the respondent, the monetary incentives for this study were instead specified as a donation to the Red Cross. Monetary incentives and donations had very different impacts on response rates. The increase in response rate due to monetary values were more significant than those due to donations, as seen in Table 5 and Table 6. For the first mailing wave, the incentive did not contribute in a noticeable way towards improving the response rate. The response rate declined for incentives below $5 and with $5 in incentive, the increase was minuscule. The trend was very different for the second mailing. There was an overall pattern, where the response rate increased with the size of the incentive. Therefore, incentives on second, and not initial, mailing was determined to produce a positive effect on response rates.

TABLE 5: GROSS RESPONSE RATE BY INCENTIVE SIZE AND CITY FROM FIRST MAILING (GREGORY, 2008)

Incentive	Wichita	Los Angeles	Both Cities
$0 Group	35.6%	6.4%	21.0%
$1 Donation to the Red Cross	30.0%	8.8%	19.4%
$3 Donation to the Red Cross	27.2%	10.0%	18.6%
$5 Donation to the Red Cross	32.0%	10.8%	21.4%

TABLE 6: SECOND MAILING GROSS RESPONSE RATES BY INCENTIVE SIZE BY CITY (GREGORY, 2008)

Incentive	Wichita	Los Angeles	Both Cities
$0	11.5%	4.7%	7.7%
$1	25.9%	13.2%	18.8%
$2	30.6%	20.0%	24.6%

Finally, the study took a closer look into the costs associated with raising the response rate. The average cost for regular mailing was $17.74 including incentives. The cost differed notably from city to city, with the cost being much higher in Los Angeles than in Wichita because the response rates in LA were much lower. On the other hand, the average cost per response for the postal card was only $1.77, significantly lower than all the other costs, and suggesting that post cards are a very cost efficient way of raising mail response rate (Gregory, 2008).

In 2009, Messer not only examined how incentives increased the response rate but also if they solved the survey data quality issue by reducing non-response error. The study utilized the Washington Community Survey, which was conducted in the fall of 2008. This study compared the effects of incentives both in mail and web surveys and found a significant increase for both modes. The mail survey obtained a 15% increase, with an even greater increase of 18.7% for the web survey (Messer, 2009).

The effect of incentives across demographics also differed in both the mail and web surveys. For mail surveys, the non-incentive respondents earned higher levels of income and used computers and the internet more often. They also had higher levels of education and a greater number of children; however, the difference was not statistically significant. As for the web survey, like the mail survey, the non-incentive respondents had higher levels of education and greater internet use. Non-incentive internet respondents generally were older and required less assistance with the internet; however, again, those differences were also not significant. Overall, the non-incentive respondents did not differ significantly from the respondents given incentives (Messer, 2009). The findings agreed with the prior studies on response rate, showing that increase in response rate does not necessarily decrease the non-response error (Keeter, et al., 2000; Curtin, et al., 2000).

4.1.2 Pre-notification Letters

While most of the studies on how to increase mail response rates focus on incentives and follow-up letters, a few have looked at the effect of the pre-notification letter. In the Kansas State University study mentioned in the prior section, the postcards were sent before the survey package with a brief overview of the purpose, timing, and agency involved in the survey. The difference between sending a postcard and no postcard were significant as shown in Table 7. The response rate difference between two cities was also significant (Gregory, 2008).

TABLE 7: GROSS RESPONSE RATES FOR POSTCARD TREATMENT FOR BOTH CITIES (GREGORY, 2008)

Treatment	Wichita	Los Angeles	Both Cities
Postcard	48.8%	20.6%	34.7%
No Postcard	39.8%	15.2%	27.5%

One such study examined its effect on mail surveys and found an 6% increase in response rate (Link & Mokdad, 2005). The Office for Survey Research conducted a more extensive experiment to test the effectiveness of sending advance letters and postcards compared to an RDD telephone survey. Their target sample was 3500 interviews with three mailing treatment groups:

1 The Control Group: Households with listed numbers that received nothing via mail (N = 4800)
2 The Letter Group: Households with listed number that were sent an advance letter (N = 4530)
3 The Postcard Group: Households with listed number that were sent an advance postcard (N = 4519)

Among these three sample groups, the response rate was highest for those receiving a letter, followed by those receiving a postcard, and finally the control. Table 8 shows that the distribution of response rate differed significantly between the letter group and control group, and was similar between letter group and the post group. The additional cost for sending letters and postcard was balanced by saving extra phone connection charges. Therefore, sending an advance letter was found to be the most cost-effective way to improve response rate. (Hembroff, et al., 2005).

TABLE 8: RESPONSE RATES OVERALL AND BY MAILING TREATMENT GROUP

		Listed Numbers (Mailing Treatment Group)		
	Total Sample	Letter	Postcard	Control
BRFSS CASRO	35.5%	34.8%	32.0%	29.4%
AAPOR RR3	33.4%	35.8%	32.8%	30.0%
AAPOR REF1	25.1%	24.8%	27.7%	27.8%

NOTE.—The total sample includes not listed numbers.

4.2 Demographics

As mentioned earlier, a low response rate need not be a fatal flaw of mail surveys, as long as the demographics of the respondents are consistent with the general population. To ensure valid and unbiased survey data, non-respondent characteristics need to agree with respondent characteristics geographically and demographically. Unfortunately, there has been no previous research on demographics or miss-represented groups tailored specifically to Ontario or even Canada; however, many are available in the United States to provide a basic understanding.

The Behavioral Risk Factor Surveillance System (BRFSS) survey demonstrated that respondents to a Delivery Sequence File (DSF) mail survey were more likely to be white, childless, living with fewer adults, and have higher levels of income and education compared to respondents to a RDD telephone survey (Link, et al., 2008). With Smyth's survey on rural areas, he suggested mail respondents in rural areas were older, more likely to be retired or unemployed, with lower education levels and income. The respondents were also less likely to be married, have fewer children, and tended to live in households with either only landline or no phone at all (Smyth, et al., 2010).

Kansas State University performed an extensive study comparing the difference between respondents' characteristics with census data for Los Angeles and Wichita.

Table 9 and Table 10 present the demographic characteristics of the census and survey respondents, respectively. There were 12% more females who responded to the mail survey compared to the census. The average age of United States in the U.S. Census was 35.3, while nearly 80% of all respondents were over 40 years of age. In contrast with age and gender, there were no significant differences amongst most ethnic groups, except for the Hispanic population, which was under-represented (Gregory, 2008).

TABLE 9: U.S.,WICHITA AND LOS ANGELES DEMOGRAPHICS, 2000

	Sex				Race				Ethnicity
	Male	Female	Median Age	Average Household Size	White	Black African American	Native American, Alaska Native	Asian	Hispanic
US	49.1	50.9	35.3	2.59	75.1	12.3	0.9	3.6	12.5
Los Angeles, CA	49.3	50.7	31.6	2.83	46.9	11.2	0.8	10	46.5
Wichita, KS	49.8	50.2	33.4	2.44	75.2	11.4	1.2	4	9.6

Source: U.S. Census Bureau[5].

TABLE 10: MAIL RESPONDENT DEMOGRAPHICS

Characteristic	Description	Number of Respondents	Percentage within group
Gender	Male	230	37.8%
	Female	379	62.2%
Age	Less than 21	2	0.3%
	21-30	33	5.6%
	31-40	85	14.4%
	41-50	108	18.3%
	51-60	146	24.7%
	More than 60	216	36.6%
Race Ethnicity	White	475	78.6%
	Black, African American	51	8.4%
	Native American	10	1.7%
	Hispanic	40	6.6%
	Asian	19	3.1%
	Other	9	1.5%
Education	Some high school	27	4.5%
	High school graduate	108	17.9%
	Some college	166	27.5%
	College graduate	180	29.9%
	Post graduate	122	20.2%

Household Size	1	168	27.3%
	2	239	38.9%
	3	91	14.8%
	4	70	11.4%
	5	31	5.0%
	More than 6	16	2.6%
Income	Less than $20,000	69	12.1%
	$20,000 up to $30,000	62	10.8%
	$30,000 up to $40,000	75	13.1%
	$40,000 up to $50,000	64	11.2%
	$50,000 up to 70,000	91	15.9%
	$70,000 up to 100,000	88	15.4%
	$100,000 up to 150,000	79	13.8%
	more than $150,000	44	7.7%

Instead of comparing survey respondent characteristics with the census, Messer compared the demographics of his Washington mail survey with the Washington population, estimated by the 2007 America Community Survey (ACS) and Current Population Survey (CPS). Mail survey respondents were found to be more likely to be older females with higher levels of education compared to the ACS and the CPS. The population was well represented in terms of marital and employment status, as well as in terms of race and income (Messer, 2009).

In conclusion, older middle class females with higher education (above high school diploma) have been found more likely to respond to mail surveys. Unfortunately, mail surveys have exhibited very similar non-response error as landline surveys, despite the absence of coverage error. This does not make mail surveys an ideal candidate for completely unbiased surveys, or address-based list frames as a complete sampling frame. However, only detailed data on respondent trends prior to 2009 in the United States were available, and the feasibility of mail frame for the TTS still needs to be investigated.

5 WEB SURVEY WITH WEB PANEL SAMPLE FRAME

The web has become a popular mode of survey data collection in both industry and academia because of the increased internet coverage in Canada, from 51.3% in 2000 to 85.8% in 2013 (International Telecommunication Union, 2015). Greater response and collection speed, convenience, lower per unit cost, and the ability to have enhanced survey design have all contributed to this increased popularity (Couper, 2000) (Couper & Miller, 2008). Despite this, coverage and non-response error are endemic in web-based surveys (Dillman, et al., 2009a), and the quality of data obtained by web survey has been a persistent concern (Lee, 2006).

Probability sampling involves the selection of a sample from a population based on the principle of randomization or chance, where each sample has an chance of being selected. Since there is no subjectivity involved in such sampling technique, the yield estimation is usually much more accurate than non-probability sampling (Statistics Canada, 2013). There have been many different types of web surveys conducted with varying sampling techniques. Non-probability sample selection methods, such as convenience and snowballing sampling, do not require a sample frame. E-mail lists and pre-recruited probability web panels can be used for probability-based sampling methods, where samples are randomly drawn from the list; this method is frequently used by universities and businesses.

Of all the web survey types listed above, convenience sampling is the least representative sampling method. Being a non-probability sampling method, the response bias is quite significant, so generalizing results to the population is difficult. Market research firms mostly utilize this type of survey sampling method, with an average response rate of around 3%. However, this type of sampling method is not recommended to be used for academic research or as the basis for transportation planning (Explorable, 2009).

Email lists have not been seen as a viable sample frame because of three main reasons. First, the Canadian Anti-Spam Legislation prohibits using emailing as the method of first contact throughout Canada and U.S.; a previous relationship needs to be established before the institution can contact samples via email (Government of Canada, 2010) (Council of American Survey Research Organizations (CASRO), 2008). Another reason is the issue of acquiring a complete frame; there are currently no updated email lists of all provincial, or even municipal, households and this would be very difficult to obtain and sustain. This frame will also encounter coverage issues; it will miss households without internet access or where household members do not have email addresses (Fricker, 2008). Conversely, over-coverage might also occur since one person can have multiple email addresses (Messer, 2009). Finally, email addresses cannot be auto-generated using algorithmic sampling methods, such as used in RDD sampling, rendering random sampling more costly and burdensome (Dillman, et al., 2009a). However, the email frame can still be used for conducting student or employee surveys, because those institutions tend to have a complete email list from enrollment and extensive internet access (Kaplowitz, et al., 2004). In fact, the average response rate for email surveys was found to be 32.8% and does not appear to be on a declining trend (Hoonakker & Pascale, 2009).

The next type of web sample frame, the pre-recruited probability-based web panel, has been wildly used by academic researchers and is currently implemented by Knowledge Networks, a large probability-based web panel, in the United States. The panel participants are recruited via RDD, and then the entire panel is equipped with a web-accessing medium irrespective of the whether the web was already accessible. Providing a method of web-access to all members eliminates the under-representation of households without internet access. Generally, the first web survey is used to collect background profiles of all members, which are then used to construct a sample frame for subsequent surveys. This type of web panel builds its frame based on households who own landlines, with cell phone-only households excluded at the beginning of selection process. The entire selection process is illustrated in Figure 18. The protocol may diminish unequal

coverage and non-probability sampling, which are inherent in other types of surveys; hence, this is the most scientific web survey mode (Lee, 2006) currently in practical application.

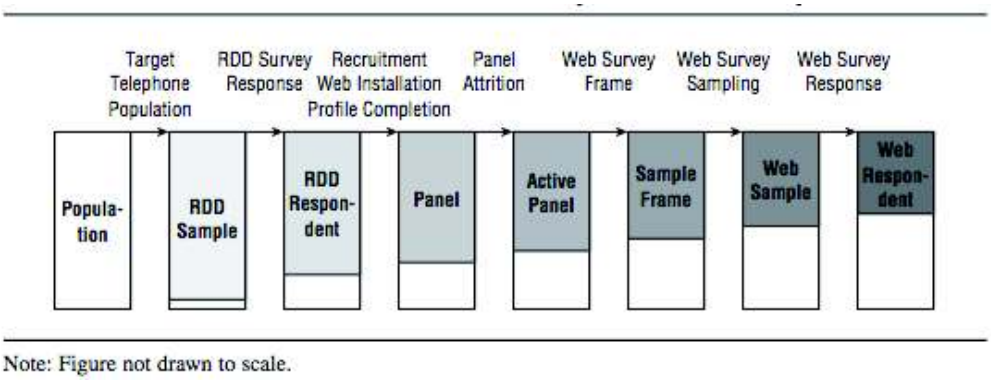

FIGURE 18: PROTOCOL FOR PROBABILITY-BASED WEB PANEL SURVEYS (LEE, 2006)

Coverage and non-response errors, however, still exist within this survey mode. As mentioned earlier, this type of web survey inherently has the same coverage bias as the RDD telephone survey. Furthermore, non-response bias from the initial contact stages, such as RDD non-respondent or panelists becoming inactive, all contribute towards the coverage bias for the final sampling frame. Because of these coverage issues, web response rates have been found to be consistently lower than those achieved by other methods, by an average of 11% (Manfreda, et al., 2006).

Lee's study evaluating non-response and coverage errors in probability-based web panel surveys attempted to evaluate the magnitude of these errors, using data obtained from a 2002 survey practicum class conducted by Knowledge Networks on 2501 households. The cumulative response rate was 5.5%, and the results showed that the coverage issue was more substantial than the non-response error. Figure 19 compares the respondent characteristics with the sample frame demographics (obtained from the first survey), as well as the covariance. The conclusion that was drawn from the study was that the coverage of the web sample frame did not appear to be sufficient. Both the population and sample covariate distribution showed inconsistencies in subgroups estimations, deviating significantly from population values. The traditional ratio ranking adjustments had a limited effect in correcting this deviation.

In 2009, Messer conducted a thorough study examining the response rate and demographics of web surveys in Washington using 9 different web panels. The web group had a response rate of 42.8% where only a URL link was sent, and a higher response rate of 46.3% if instructions were sent along with the link. Comparing the web demographics with those of mail respondents, it was found that web respondents were more likely to live in an urban area, have a greater number of children, and be younger. Next, comparing web respondent demographics to Washington's general population, web respondents had higher levels of education and larger household sizes. They were also more likely to be married with children in the households. The demographics of the web respondents appeared to be more representative of the general population in terms of age and gender than either mail respondents or combined mail and web respondents (Messer, 2009). Demographics obtained from BRFSS online respondents also showed that web respondents are more likely to be younger, married, have children and have higher levels of education and income (Link & Mokdad, 2005). A separate 2008 study reported similar differences in web respondent demographics (Rookey, et al., 2008).

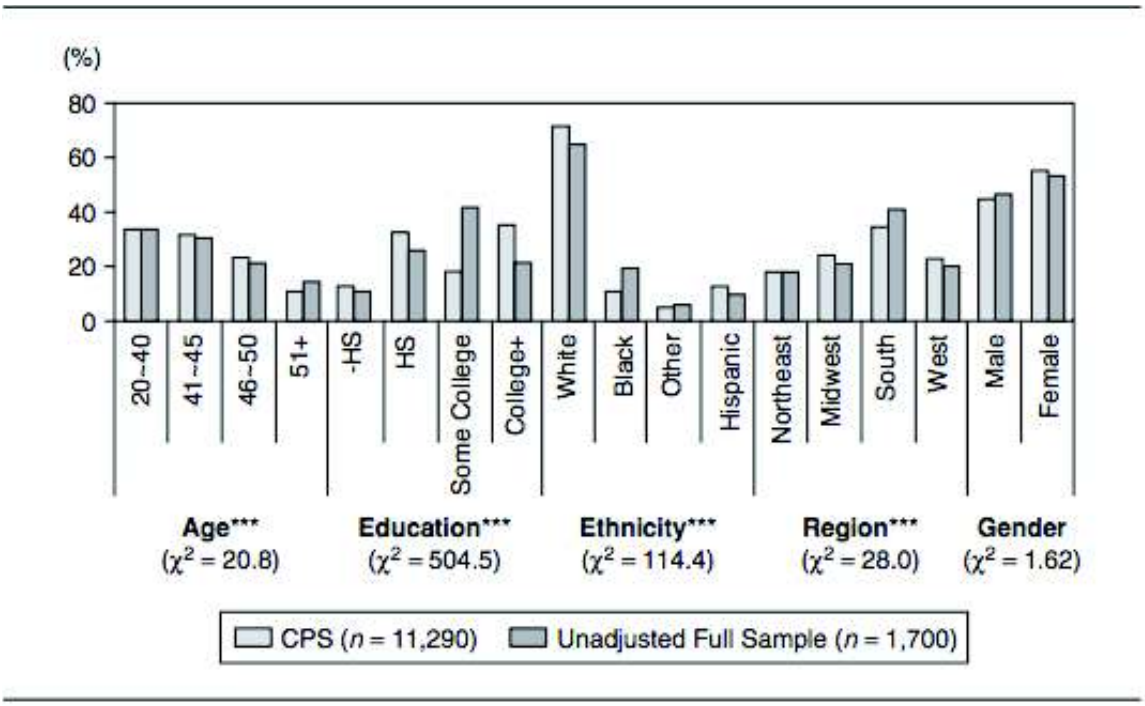

FIGURE 19:DISTRIBUTION OF COVARIANCE FROM CURRENT POPULATION SURVEY AND UNADJUSTED FULL SURVEY SAMPLE (LEE, 2006)

Having examined the common web survey methods, it appears that these generally have a large coverage bias, meaning that it is difficult to obtain a representative frame. However, the demographics of the respondents in the mentioned studies are often closer to the census demographics than mail or landline frame demographics. Some of the available web panels in Canada include IPSOS, PMG intelligence, and Ekos. Most of these panels use telephone RDD method to recruit their panelists and conduct surveys online parallel with telephone surveys for households without internet access. Based on an interview with an IPSOS executive, it was learned that the entire panel consists over 200,000 Canadians with around 10,000 located in the GGH. The typical response rate of the web panel has been about 30%, with the respondents more likely to be middle-class and middle-aged women. Contrary to the studies above, the demographics of web panel in Canada had greater similarity with the landline frame, in that they also under-represent the young male demographic (Howell, 2016).

Based on the examination presented in this section, the probability-based web panel frame might not be ideal to be used as the only frame for conducting a web survey because of its coverage bias and significantly lower response rate. However, the advantages of web surveys, namely their cheap cost and potential for interactivity, make them ideal candidates for mixed-mode surveys, or as the mode for satellite surveys to raise the response rate of hard-to-reach groups, such as students. The weaknesses of web frames can be mitigated by combining them with other sampling frames. Section 6 focuses on the benefit and drawback of combining multiple frames and how to account for an error produced by integration of multiple frames.

6 MIXED MODE SURVEYS

The decline in RDD response rates has contributed to the increasing use of mixed mode surveys. In mixed mode surveys, two or more survey methods are implemented for survey data collection. The goal is to improve respondent demographic representativeness by targeting different population groups with the varying methods. A substantial amount of research has found that mixed mode surveys can reduce both non-response rate and non-response bias (Dillman, et al., 2009a; Link & Mokdad, 2005; Groves, 2006; de Leeuw, 2005; de Leeuw, et al., 2008).

The decision to use mixed mode surveys typically has involved careful consideration of coverage, non-response, and measurement error (Dillman, et al., 2009a). There are some crucial questions that need to be answered regarding these issues to determine the effectiveness and quality of the combined survey mode (Ampt & Stopher, 2005).

- Will adding a new method of data collection (frame) achieve a better response rate?
- Will adding a new method of data collection decrease response bias?
- Will the additional data give better trip estimates?
- Will it be cost efficient?

The answers to these questions are key to justify the extra cost and effort involved in the use of additional frames and determine whether the specific mixed mode survey is a better approach for a possible TTS 2.0 data collection program than the use of an individual frame type.

Many studies show positive results with respect to these questions. In 1999, Shettle and Mooney reported significant improvements by contacting potential respondents via mail, followed by telephone to non-respondents, and then finally following up in person. This method achieved a response rate of 68% for 4 mail contact attempts with cash incentives, another 13% from telephone follow-up, and an additional 7% from in-person interviewing (Shettle & Mooney, 1999). The 2000 U.S. census supplement survey was also implemented with a similar sequential strategy and achieved an overall 95.4% weighted response rate. The response rate was highest for mail, followed by computer-assisted telephone interview (CATI), and, finally, computer-assisted in-person interview (Griffin & Obenski, 2002). Link and Mokdad also found that by offering web or mail as an alternative to a CATI-only survey method increased response rates significantly, especially where mail was the alternative method (Link & Mokdad, 2006).

However, these conclusions have not been consistent across all studies, with some finding that where a choice of mode was permitted, the response rates actually experienced a drop or stayed the same (de Leeuw, 2005) (de Leeuw, et al., 2008). For example, Dillman, Clark and West in 1995 did not find any improvements in response rates when respondents were offered a choice to respond by either mail and phone. Balden (2004) also reported similar results when offering response method by mail, the web, and interactive voice response (IVR) (Balden, 2004). In the 2001 American Community Survey, Griffin, Fisher, and Morgan found that providing a choice between mail and web obtained response rates 5.8% lower than a mail-only survey (Griffin, et al., 2001). This could be because when too many options were provided, the complexity of the decision-making process overwhelmed survey respondents; in this case, they might have opted to instead choose to not participate (Schwartz, 2004).

In 2006, Link & Mokdad examined the demographics of mixed mode surveys. They found that the respondents to the web/CATI and mail/CATI surveys were different than the target population, as reported by ACS. The respondents to both types of mixed mode survey were over-representative of older, white women with higher levels of education and income compared to the members of the target population (Link &

Mokdad, 2006). In a follow-up 2008 report, similar findings were also reported between RDD telephone and DSF mail respondents compared to the target population (Link, et al., 2008).

Some of the answers on how adding new methods of data collection could affect response rate and response bias can be found in Dillman's report on a mixed mode survey conducted in Washington State. The report investigated how survey answers differed when the survey mode was changed. Most importantly, it thoroughly examined the impact of changing survey mode on response rates. The study was conducted in 2 phases with 8999 sample households separated into 5 treatment groups. The first phase utilized mail, telephone, IVR and web surveys, while the second phase followed up via either telephone or mail. Table 11 confirms that the use of multiple survey mode did raise response rate, especially when the response rate for the first mode was fairly low, as observed for web and IVR modes. The high response from mail survey could be due to a short questionnaire, $2 incentives and the visually attractive design of the questionnaire (Dillman, et al., 2004).

Unfortunately, for mixed-mode methods, obtaining a higher response rate is accompanied by an introduction of varying measurement/instrument error between modes. The research has found that aural modes give more extreme responses on the positive end of a scalar question compared to visual modes (Dillman, et al., 2004). For example, when a question was asked about satisfaction on a scale from 1 to 5, responses via a telephone interview were more likely than other methods, such as on mail or the web, to obtain a response of either 1 or 5. This result is consistent with prior research which reported that different survey modes produced different answers to the same question. In particular, the telephone interview has a greater positive response to scale questions than web surveys (Chritian, et al., 2008).

The success of the second mode in reducing potential non-response error for more accurate demographic distribution of respondents appears to be small. In Dillman's Washington study, there were no significant differences in the respondent characteristics of the two phases across all treatment groups for incomes. Switching survey mode did not bring in respondents with significantly different reported education levels. All treatment groups appeared to have more men reported. Not only did the demographics of a certain survey mode not change based on treatment groups or phases, the overall respondent demographics differed significantly from the non-respondent demographics of the survey. Therefore, Dillman concluded that switching to a second mode does not reduce the non-response error with an increase in response rate (Dillman, et al., 2004).

TABLE 11: RESPONSE RATES OF ALL TREATMENT GROUPS (DILLMAN, ET AL., 2004)

Groups	Original sample size	Phase 1			Phase 2			Total	Improvement in response rate
			n	%		*n*	%	%	%
Treatment 1	2000	Mail	1499	75.0	Phone	157	31.7	82.8	7.8
Treatment 2 (Form A)	1500	Phone	651	43.4	Mail	1094	66.3	80.4	37
Treatment 3 (Form B)	1499	Phone	667	44.4					36
Treatment 4	2000	IVR	569	28.5	Phone	438	35.9	50.4	21.9
Treatment 5	2000	Web	253	12.7	Phone	700	44.9	47.7	35

One year later, in response to deficiencies in their traditional face-to-face personal interview survey method, the 2005 Sydney travel survey studied the mixed method data collection mode. As with other surveys, the Sydney survey had suffered from a significant decline in response rate from 79% in 1981 to 55% near 2005. They also examined the causes of the falling response rate, and if a mixed-methods data collection effort would help solve this global issue. This time, the investigation was more focused on travel surveys, particularly if the collected trip data would vary across survey modes (Ampt & Stopher, 2005).

A schematic of the mixed-method survey options used by the Sydney survey is presented in

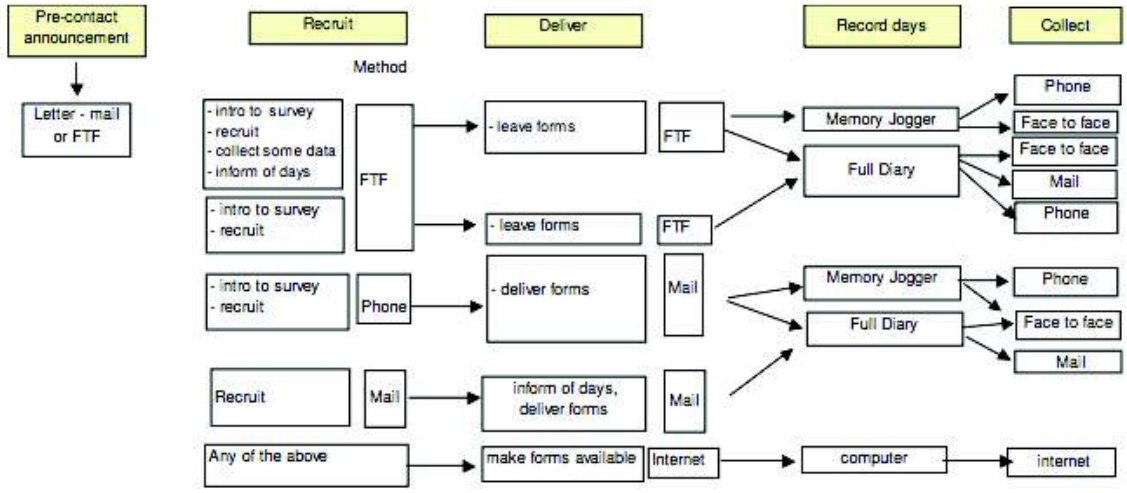

Figure 20. It demonstrates the combination possibilities of different survey modes in the various data collection stages. In contrast with Dillman's study, the Sydney survey also looked into introducing a new frame to the survey sample, rather than recruiting all respondents using RDD.

However, there is an additional concern when introducing an extra sampling frame, which is the introduction of a different set of non-response biases. For example, suppose that a face-to-face survey method is planned using an address-based frame with a known bias against frequent travellers. Next, suppose that a telephone-based survey using a directory list frame was now added as a given option of responding, but it was known to be biased against the elderly and the young, and against frequent travelers. In this situation, not only has the introduction of an additional frame not solved the non-response error, it has also introduced a bias against the young and the old, with or without a higher response rate (Ampt & Stopher, 2005).

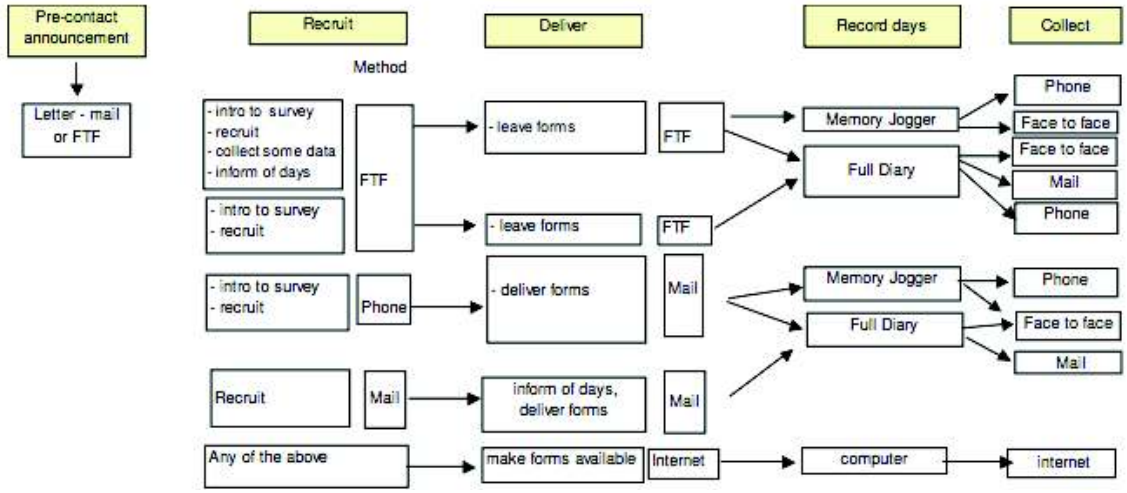

FIGURE 20: SCHEMATICS OF MIXED METHOD SURVEY OPTIONS (AMPT & STOPHER, 2005)

Non-response bias can also affect the data quality for trip information. Using the previous example, face-to-face interviews tend to under-represent frequent travellers, which means that the total number of trips would be under-reported. Additionally, telephone interviews tend to reach more mobile elderly individuals and less mobile teenagers, which also hinders the quality of trip data. Table 12 details the number of trips reported per person by using different survey modes, illustrating the measurement bias between survey modes. The Sydney survey report also suggested possible field tests that could be conducted in order to answer how the use of additional survey modes and survey frames would affect response rate, response bias, and trip information. These are discussed in detail later in the report.

TABLE 12: TRIPS PER PERSON (AMPT & STOPHER, 2005)

Survey	Face-to-Face	Telephone	Postal
HTS, Sydney 2002[1]	4.2		
VATS Pilot, Melbourne 1994[2]	5.3		3.5
Grenoble, France 1985[3]	4.2	4.1	
The Netherlands, 1983[4]	3.3	3.7	
The Netherlands, 1984[4]	3.5	3.5	
Dutch National Travel Survey, 2000[5]		3.6	3.1

6.1 Mail as Initial Contact Method

One study found that using mail as the initial contact mode could bypass many of the coverage, sampling and ethical issues involved in sampling and surveying (Dillman, et al., 2009a). Messer found that using a mail follow-up to a web survey had a substantial positive impact on response rate, while a web-based follow-up to a mail survey produced negligible improvements. The average increase in response rate with mail follow-up was 15.8%, while the increase in response rate with the internet follow-up averaged 2.1%. In this case, a mail-only mode obtained the highest response rate. The demographics of these mixed modes were also different; a greater proportion of web respondents were obtained when the web was the first mode to be offered compared to the reverse. Since the demographics of web respondents differed significantly from mail respondents, adding a mail survey mode to the web survey, or vice versa increased demographic coverage and reduced non-response. It was found that the mixed mode survey did result in more representative respondents in terms of employment and marital status, while being similar in race and income level, compared to mail or web-only modes. However, the web-only mode had better representation of age and gender, while all three over-represented people with higher education levels.

Using mail for the initial contact, while providing both mail back and web survey options, was the survey method used by the Canadian census. It is one of the most promising methods for examination in the TTS 2.0 project, in terms of both higher response and coverage rates. However, the response rate of the mixed-mode method in Messer's study detailed earlier in this section did not exceed the mail-only response rate, and the additional respondents did not contribute to increased representativeness. As a result, it is difficult to conclude if mixed mode survey would indeed reduce non-response errors and increased survey data quality (Messer, 2009). As the census is mandatory, a field test might be required to examine the non-response error and response rate from a mail-web dual-mode survey with less authority.

7 CELL PHONE AND LANDLINE DUAL FRAME

With the growing ubiquity of smartphone technology (84.9% of the households in 2013 reported ownership of at least one cell phone), the population, especially the younger generations, has become more dependent on their cell phone and less on landlines (Statistics Canada, 2015). This has resulted in a special kind of household; those households using only cell phones with no landline labelled as cell phone only (CPO) households. The dramatic increase in the number of CPO households (from 8% in 2008 to 21% in 2013) (Government of Canada, 2012) has decreased landline frame coverage rapidly and significantly.

Finding a new frame that covers all the households has become essential. The cell phone and landline dual frame has become the most common survey sampling frame in the United States, utilized by both the Pew Research Center and the National Health Survey (McGeeny, et al., 2015). There are generally two approaches to design the dual frame: overlapping and non-overlapping. The non-overlapping approach screens cell phone samples for CPO households and samples from both CPO households and landline households to avoid double counting.

Conversely, the overlapping design calls for a fixed proportion of landline and cell phone numbers. For example, Pew Research Center increased their cell phone percentage to 65% in 2015, a huge leap from the 25% at the beginning of their use of dual frames in 2008 (Pew Research Center, 2012). The combination of 65% cell phone and 35% landline was expected to contain 37% of CPO households, which is still short of the target of 46.5% in the United States (Keeter, 2015). Canada has a much lower proportion of CPO households of around 20% (Government of Canada, 2012), therefore a 40% cell phone and 60% landline combination would be sufficient to obtain similar proportions (Pew Research Center, 2012).

Both approaches have their advantages and disadvantages. The overlapping design is more cost effective without the screening process, but it requires weights to account for the fact that some units have a chance to be selected multiple times. This makes the data analysis stage more difficult. On the other hand, the non-overlapping approach reduces coverage error and does not require weighting because the frame covers the under-represented subgroups independently. The weakness of the non-overlapping approach is the possibility of increased non-response percentage because cell phone samples tend to have a lower response rate than comparable landline samples (Miller, et al., 2012). For a more detailed calculation on weighting approaches to handling overlapping, please refer to the prior 2015 Report on the Current State of Landline Survey Methods (Pulikanti, et al., 2015).

The studies listed below utilized cell phone and landline dual frames, investigating the feasibility of using a dual frame with respect to response rate, demographics, the proportionality of CPO households required for unbiased estimation, and incentives required. In 2007, Brick et al. evaluated the feasibility of including cell phone numbers in an RDD survey in the United States (Brick, et al., 2007). The survey included $5 and $10 dollar incentives via text message to establish credibility before a call was made, and obtained a response rate of 26.5% for cell phones and 38.6% for landlines, computed using the AAPOR 2006 RR3 definition[5]. The study found that the use of a text message did not increase the cell phone response rate (text message: 26.2%, no message: 26.5%), but higher incentives did result in a higher response rate ($10: 29.9%; $5: 22.7%). Their conclusion was consistent with an earlier study (Steeh, 2004). It was concluded that augmenting the sample frame with cell phone numbers is feasible, but there are serious challenges such as low response rate and high refusal rate that need to be addressed.

[5] RR3 estimates what proportion of cases of unknown eligibility is actually eligible. For detailed calculation please refer to (American Association for Public Opinion Research, 2015)

In a more recent 2011 study, Hu et al. looked at the feasibility of cell phone surveys in more depth by using information from the ongoing monthly BRFSS data collection program. In this case, the frame used a non-overlapping approach, where the cell phone proportion of the total sample was calculated from the CPO household status using the following equation:

$$Cellphone\ Proportion = \frac{\mathrm{P}}{P + (1 - P)\sqrt{\frac{Cost\ Cell - only}{Cost\ Landline}}}$$

where P is the proportion of adults that use only a cell phone. As an example, when P is 0.2, only 10% of the household interviews needs to be cell phone-only households.

The overall cell phone response rate over 18 U.S. states in 2011 was 24.8%, and some significant differences in demographic characteristics between cell phone and landline respondents were observed. The differences included the percent of respondents who were:

- Male (cell phone: 59.4%; landline: 46.7%, p< 0.001).
- Non-Hispanic White (cell phone: 57.3%; landline: 66.8%, p<0.001)
- Between 18 to 34 years of age (cell phone: 64.2%; landline 24.8%, p<0.001).

There also existed major differences regarding the socioeconomic status of the two respondents, including the percent of respondents who:

- Were not working or retired (cell phone: 16.2%,; landline: 36.6%, p<0.001).
- Had annual income less than 35,000 (cell phone: 48.5%; landline:31.9%, p<0.001).
- Were never married (cell phone 43.8%;, landline: 17.3%, p<0.001).

Finally, there were no differences in education levels for the two groups of respondents. The report concluded that including cell phone numbers in telephone survey was feasible, but it was costly and produced low rates of participation; additionally, response rates varied quite noticeably from state to state. (Hu, et al., 2011)

Pew Research Center examined the cost and benefits of full dual frame telephone surveys. The 2008 report focused on the difference in demographics of dual households reached by cell phone and by landline. Using a combined data set from 3-4 previously conducted surveys by the Center, it was concluded that the differences between dual cell phone/landline users reached by cell and landline were rather modest. Some of those differences included more men reached by cell than landline (56% compared to 47%), more Hispanics being reached by cell phone, and a generally younger population for dual cell phone/landline users reached by cell. All other demographic measures had minor differences; however, as seen in Table 13, it was clear that hard to reach subgroups were better represented through the cell frame. The overall data reviewed strongly suggested that the difference between dual users reached via cell phone and those reached via landline were not significant. Therefore, dual users reached by either landline only or cell only would be representative of this segment of the population (Keeter, et al., 2008).

Table 13 presents how the cell phone only household demographic not only differed significantly from a landline, but also from those with both cell and landline. For instance, most cell-only respondents lay between ages of 18-49, whereas for dual landline/cell users, the respondents were older and lay between ages 30-64; for respondents of age 65+, more were found to be landline-only users. Next, there were more men in the cell respondents than among landline respondents, and cell respondents were more diverse in ethnicity than landline respondents. Finally, the socioeconomic status of cell-only respondents was very similar to the landline-only respondents, which were primary low to middle class. On the other hand, those with both cell and landline phones were more likely to be college educated with a high annual income (Keeter, et al.,

2008). Similar demographics to the previous studies with more young male respondents was once again detected, contrary to the under-representation observed in the landline respondents.

Moreover, the report also examined if a substantial amount of dual landline/cell users were functionally cell-only. This was done to check whether double coverage needed to be eliminated. The 2007 survey asked about the frequency of dual landline/cell users using their landline and cell phones and suggested that while the dual landline/cell users were cell-oriented, they were not functionally cell-only and could be reached by landline.

As cost is a very crucial factor determining the feasibility of a sample frame, Pew Research Center also looked into the call-center effort required for surveying using each frame. On average, 3.5 calls were required to reach landline-only users, 3.4 calls to reach landline-oriented dual landline/cell users, and 4.3 calls to contact more cell-oriented dual landline/cell users by landline. Overall, more attempts were necessary to complete the survey for dual-technology users who were contacted by cell phone (4.2 calls for cell oriented and 3.7 for landline oriented). In terms of reaching cell-only respondents, previous studies suggested that the cost would be raised by 4-5 times compared to landline-based interviews because of the screening process. The productivity (hours spent conducting interview/ total hour spent) was also much lower with the cell phone compared to the landline frame (27% to 39%), which translated to a higher cost per number (Keeter, et al., 2008).

TABLE 13 DEMOGRAPHIC COMPOSITION OF THE LANDLINE AND CELL PHONE PUBLICS

Demographic Composition of the Landline and Cell Phone Publics
(three dual frame surveys combined)

Proportion of U.S. adults[1]	26%	60%		14%
	Landline only	Landline & cell interviewed on... Landline	Cell	Cell only
	%	%	%	%
18-29	11	12	17	47
30-49	21	37	41	36
50-64	27	31	29	12
65+	38	18	12	4
Male	47	47	56	61
Female	53	53	44	39
College grad	23	42	40	25
Some college	22	25	24	28
H.S. grad	40	28	29	35
Less than H.S.	14	5	6	12
$75K or more	14	36	36	18
$50-74,999	9	16	18	13
$30-49,999	19	19	20	24
Less than $30K	37	15	16	37
White	78	83	80	69
Black	14	10	12	18
Asian	1	2	3	5
Other/Mixed	4	4	4	5
Hispanic	8	6	10	15
Protestant	55	54	53	48
Catholic	22	22	24	19
Other	6	8	7	8
Unaffiliated	14	14	14	24
Married	40	63	60	26
Never married	21	15	23	51
Parent of minor	16	32	35	26
Renter	28	15	20	60
Get more calls on...				
Cell phone	-	30	48	-
Landline	-	43	26	-
Both equally	-	27	25	-
Sample size (for most vars)	(1235)	(3020)	(968)	(600)

Figures based on unweighted data from 3 surveys
[1]Source: Extrapolated from 2007 National Health Interview Survey conducted by the National Center for Health

In 2010, Pew Research Center conducted another similar survey to study the demographic differences between cell phone and landline respondents. The conclusion was again very similar to those found in previous studies. The landline sample was missing the younger generation while over-representing the older generations. As demonstrated in Table 14, only 7% of the sample were between age 18 and 29, but 31% were individuals that were 65 and over. On the contrary, the cell phone sample, which has very different characteristics from the landline sample, had 29% of its population between the ages of 18 and 29, and only 10% of the 65 and older group; the Hispanic group was also better represented in the cell phone sample (Keeter, 2011).

TABLE 14: DEMOGRAPHICS OF LANDLINE AND CELL SAMPLE (KEETER, 2011)

Pew Research Center 2010 Surveys	Landline Sample (N = 10,723)	Cell Sample (N = 5,352)
Sex		
Male	41%	55%
Female	59%	45%
Age		
18 to 29	7%	29%
30 to 49	25%	33%
50 to 64	34%	27%
65 and older	31%	10%
Race/Ethnicity		
White	81%	71%
Black	10%	14%
Hispanic	6%	11%
Education		
Less than high school	7%	9%
High school graduate	27%	37%
Some college	27%	29%
College graduate	39%	35%

Statistics Canada provided the demographics growth in the U.S. from 2007 to 2010 in Table 15. Growth in cell phone users was observed in all age groups, more prominently in the younger generation, below the age of 34. Within three years, the cell phone-only households nearly doubled, with both genders showing consistent growth. The socioeconomic status distribution of the cell phone-only households remained similar, with the mostly middle-to-lower classes consisting of a growing number of students and homemakers. Cell phone-only households consisted of younger male respondents who were more likely to be renters and/or students (Government of Canada, 2012).

TABLE 15: DEMOGRAPHIC PROFILE FOR CELL PHONE ONLY HOUSEHOLDS IN U.S.A. (GOVERNMENT OF CANADA, 2012)

National Health Interview Survey	2007	2010
Sex		
Male	14%	26%
Female	12%	24%
Age		
18 to 24	28%	40%
25 to 29	31%	51%
30 to 34	17%	40%
35 to 44	11%	27%
45 to 64	7%	17%
65 and older	2%	5%
Education		
Less than high school	15%	29%
High school graduate	12%	24%
Some college	11%	23%
Employment status		
Employed	15%	29%
Student	21%	33%
Homemaker	10%	23%
Household Type		
Owner	7%	16%
Renter	31%	47%
Household Income		
In poverty	9%	39%
Near poverty	11%	33%
Higher income	16%	22%

All the studies detailed in this section have shown the feasibility of using a dual cell phone/landline telephone frame in the United States. The dual frame is an efficient way to increase representation of underrepresented demographics from the traditional landline frame (namely men between ages of 18 and 34). It helps correct the problem of non-response bias in the landline frame, because of increased coverage and the complementary demographics. Another advantage of this frame is that it has been widely

implemented in the United States. As such, a systematic approach has been found and can be utilized in the TTS 2.0 survey.

However, there are also many challenges if it is to be implemented in a future TTS. One major issue is the cost. Because the cell phone frame in Canada is not as developed as in the United States, there currently are limited sources of cell phone frames. In Canada, the cost per cell phone number is around $4 (ASDS, 2016), and so it is very costly, especially for a large survey like the TTS. Another issue is that cell phone surveys tend to have a lower response rate, although the response rate does not necessarily impact the accuracy of data, and the demographics of the cell phone frame complements the landline. A field test tailored to the GGH region is needed to compare the demographics of the dual frame to the population.

8 ALTERNATIVE FRAMES

As the existing landline-based sampling frame that has traditionally been utilized by the TTS becomes less and less representative of the population of the GGH, the feasibility of incorporating alternative sampling frames into the TTS design must be investigated. Technological advancements, and a substantial increase in the amount of data that is being collected by private corporations, public entities, and other organizations, presents the opportunity to incorporate these sets of data into the TTS design. This could be done either as part of a core-satellite framework or as the sole sample frame of the TTS. These alternative frames not only grant access to some of the hard-to-reach groups, they also provide a way to increase credibility or authority behind the survey and, thus, may aid in increasing response rates.

8.1 Post-Secondary School Email List Frames

Post-Secondary school email lists are a good example for alternative frames because the list has the email contact information for all students within the school and, therefore, is complete. Some schools also have student's phone number and addresses which can be used as an additional contact method. Another advantage of the frame is its special demographics. Post-secondary school students are mostly between the ages of 18 and 34, which corresponds to the hard-to-reach group in the landline frame. Therefore, it is a good candidate for the alternative frame, especially when incorporated as part of the core-satellite framework. Of course, not all young adults are post-secondary students, and so the special nature of this group needs to be kept in mind. Nevertheless, post-secondary students are a significant group within the travelling public and the ability to target them explicitly is a promising option.

StudentMoveTO was a recent survey which utilized university email lists as its sample frame. StudentMoveTO was a 2015 transportation survey with the goal of promoting and improving mobility for students within the Greater Toronto Hamilton Area (GTHA). The survey collected data at theCity of Toronto's four universities (OCAD U, Ryerson University, University of Toronto and York University), with a combined student population of 184,000, and achieving an overall response rate of 8.3% (Student MoveTO, 2015). StudentMoveTO has demonstrated the feasibility of comprehensively surveying post-secondary students via the web. It could readily be expanded beyond the original participating four universities to encompass all post-secondary (universities plus colleges) within the GGH, thereby providing a high-quality supplementary sampling frame within a mixed-frame TTS survey process.

8.2 Employee Surveys

Employee surveys are another category of surveys that utilize an alternative sample frame. Generally, this frame is provided by employers and contains phone numbers and/or email addresses of the employees. Employee surveys can access a much larger population compared to other types of alternative frames, as the labour force in Ontario for July 2016 was 7,447,000 at an employment rate of 64.4% (Statistics Canada, 2016). Some demographics of the employees, including education, age, and gender, differ from the population. Employees are more likely to have higher levels of education as the employment rate increases with education level (with university credentials: 81.6%, without 55.8%). The employee population is also more likely to under-represent people over the age of 65 (age of retirement) (Statistics Canada, 2015). Some gender inequality also exists in the labour force, with women historically being under-represented (Statistics Canada, 2016).

The Statistics Canada workplace and employment survey used the same frame from 1999 to 2006. They selected a sample based on the business list obtained from Info Canada. Info Canada's business list has information available on all businesses, including business activity, address, business contact (phone number,

name, title), the number of employees (part time/ full time), and size of business space. The list had 78,859 businesses for the City of Toronto, compared to the City's 2015 Employment Survey of 75,710 establishments. The discrepancy may have been caused by the fact that the business list from Info Canada is updated monthly, whereas the Toronto Employment Survey is conducted annually. As a result, it can be speculated that the frame is nearly complete. As for the GGH, there are 216,613 businesses, and the cost for 5% of the population is around $2,700. This list can be stratified based on, for example, geographical regions and a number of employees, for sampling purposes at an additional cost of $250 to $500 (Chung, 2016).

Another potential frame for employee surveys is from business groups and Business Improvement Areas (BIA). For example, SMART Commute has a workplace program that helps inform employers and commuters about their commuting choices. The program includes 330 employers, encompassing 721,000 employees and post-secondary students. In their 2014 Commuter Attitudes survey for the Greater Toronto and Hamilton Area, the survey appeared to over-represent the 45-64 age group, and under-represent ages 65 and above. Move the GTHA is another group of organizations working together to build awareness and engagement in support of investment in the GTHA transportation system.

BIAs are associations of commercial property owners and tenants within a defined area who work in partnership with the City of Toronto. There are 82 BIAS in Toronto, including Waterfront, Kensington Market and the Financial District, representing over 40,000 businesses. However, the BIAS are not representative, excluding many industrial businesses and businesses from small municipalities (e.g. Waterloo only has 1 BIA).

The coverage of business groups and BIAs all seem to be incomplete, which leaves Info Canada's business list as the best currently available sample frame for reaching employees. However, reaching employers through organizations such as BIAs can promote and encourage employee participation because of their established authority; it is also easier to distribute benefits and incentives through these organizations. A similar rationale applies to encouraging participation of employees; surveys through employers may provide more credibility and increase response rate relative to directly contacting employees (assuming that a sample frame for doing so existed). Some important issues with employee surveys are how to encourage the employers to cooperate with TTS and the degree of coverage of GGH households which an employment-based survey would generate. Both questions cannot be answered without a well-planned field test, which is discussed in the last section.

9 ALTERNATIVE HOUSEHOLD SAMPLING STRATEGIES

Prior sections of this report have highlighted some major issues in the current methods of sample frame construction, sampling, and recruitment of households for household travel surveys. Based on a literature review of prior surveys and a geographic analysis of the 2011 TTS data, clear problems were identified in the use of a landline-based sample frame No strong geographic patterns in the demographic misrepresentations within the resulting household sample are observed, which illustrates the systemic nature of the problem. The conventional approach of using a household address/phone database as the sample frame needs to adapt to cope with changing contexts of urban demography. Surveys around the world have attempted to deal with these deficiencies using various other frames (various combinations of landline, cellphone and mail frames), as well as using multiple contact and response modes. There remain, however, gaps in knowledge with respect to the representativeness of the resulting respondents, particularly because of unknown non-response bias in these other frames.

Moving forward, two general methods are proposed for further examination towards addressing these issues with the TTS sample frame. The first follows from the methods used in prior surveys, namely the use of multiple frames that may overlap to provide coverage for demographics missing in the original landline frame. The second is a new approach proposed by the TTS 2.0 team members, utilizing alternative sample frames not normally considered for household surveys, in order to increase the response rate of specific groups based on the idea that the method of contact plays a significant role in the likelihood of response. While these are described separately in the following sections, a final approach is more likely to be composed of some hybrid of these approaches based on their coverage identified through further study.

9.1 Multiple Frame Sampling

In a multiple frame survey, as described in prior sections, multiple list or area frames are joined to form a combined frame. Based on the information available for each frame, sampling from the frames can be done under either the assumption of overlaps existing or no overlaps. For example, for a dual landline-cellphone frame, separate lists are obtained for landline numbers (normally with addresses), while the cellphone frame uses either RDD or pruned pre-dialed numbers, which may mark whether the household is CPO. In the former case, some overlap may exist between the two frames which needs to be accounted for; some example procedures for this were presented in the 2015 cellphone report (Pulikanti, et al., 2015), with more detail found in a guide by Statistics Canada (Lohr, 2011). In other cases, multiple frames may be appropriate where a complete frame is available but would require be too costly to implement and/or cannot be sampled efficiently due to low response rate. Conceptually, multiple frames can be depicted using Venn diagrams, showing frames which are mutually exclusive, overlapping and subsets (Figure 17).

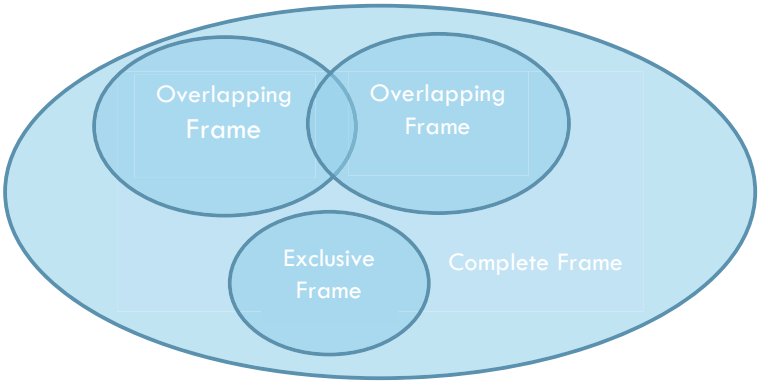

FIGURE 21: MULTI-FRAME SCHEMATIC

For the TTS, three household frames are possible: mail, landline and cellphone. Of these, the mail frame is complete but may not have an associated telephone number for follow-up/reminder. The landline frame generally has an associated address. Finally, the cellphone list can be constructed via RDD or by purchasing a sample from a sample house who has taken the time to screen numbers. The former approach may be cheaper provided that the connection and response rate are not too low, while the latter is expensive but may allow for higher response rates and may provide addresses for dealing with overlap with other frames.

A multi-frame would involve some combination of these three frames; however, as time progresses, it is expected that the level of landline penetration will drop. It is not expected to vanish entirely, especially for higher-income households, which are more likely to have both a landline and cellphones. While this does not change the overall framework of dealing with multiple frames, care has to be taken to account for differing issues in non-sampling error, particularly the cellphone frame which is expected to dominate in future years. In addition, the issue of the cellphone frames generally not having associated addresses makes sampling using geographic stratification, or ensuring proper geographic and not just demographic representation, more difficult for the purpose of creating trip origin-destination (O-D) matrices. As a result, additional research is required to compose an appropriate multi-frame for the TTS and deal with the issues of overlap and coverage; as part of the latter is the need to deal with the individuality of cellphone-based lists compared to the household-based focus of the TTS.

One component of this research will be an analysis of data collected by the 2016 TTS, once these data are available. In a break from past TTS practice, the 2016 TTS utilizes a combined mail, landline and cellphone (via RDD) frame. As such, a detailed examination of the effectiveness, including response rate and demographic profile, from each of these frames will be useful in examining issues in this method in the GGH context. Section 10 describes this analysis in greater detail. Based on this analysis, conclusions will be possible on the level of demographic and spatial coverage, as well as obtainable response rates, provided by using a multiple list sample frame. Recommendations may also be possible on how such a combined frame could be improved based on any identified deficiencies, and any additional required field research.

9.2 Inverted Sampling Via Alternative Frames

In the presence of new and evolving contexts (single-person households, shared residences, households without landlines and with multiple cell phones, etc.), there will be an increasing portion of households that will be difficult to reach through conventional household-based sample frames. This is compounded by growing levels of non-response even when reaching these groups is possible. In such contexts, accurate estimates of coverage (both over and under-coverage) across demographics becomes difficult, if not impossible. Because of these concerns with reaching households directly via traditional or even newer methods, an alternative approach, an ‘inverted sample frame' is suggested for consideration.

In the ‘inverted sample frame’ method, individuals and households would be recruited via their place of employment, institution (e.g., school) or transportation-focused member organizations. The main motivation for this approach is to try to reach households that have been traditionally harder to reach via household-based frames. Another consideration is to deal with the dropping enthusiasm from the public in answering surveys, particularly detailed ones, by delivering requests via organizations that may hold more sway among potential respondents. Such a method could be used as the sole combined frame, depending on coverage, or as a supplement to a household-focussed frame(s).

This approach is dependent on the ability to reach employees, students or members of companies or organizations via their complete email lists. As anti-spam law forbids direct contact with an individual without a prior connection, and it is highly unlikely that organizations would release their contact lists externally (either telephone or email), organizations willing to be a part of the sample frame would need to contact their employees, students or members directly. In this situation, email would be the only method that would be feasible given time and monetary costs, as would the response method of the survey via the web, smartphone app, or another low-cost method . Whether the linked website would collect contact information, basic demographics and home location for controlled sampling or if an uncontrolled sampling method would be used with post-collection correction is an open question for future study. Mechanisms to ensure a single entry per household would also be required, with the selected individuals completing the survey by providing the travel information of all household members.

9.2.1 Considerations for the Inverted Sampling Method

Assuming sampling is controlled after collecting basic info of potential participants, the feasibility of adopting this approach to produce a sample that is both large and representative of the target population depends on a number of factors. If the sample is to be derived from a single source (e.g. a business list), the degree of which the frame itself is representative of the population plays a significant role in the quality of the sample. If the frame does not include information pertaining to the members of a particular sub-population, a sample derived from said dataset cannot truly represent the population. If the sample is to be derived from a set of disparate frames, then an additional problem can arise, namely the presence of multiple entries that pertain to the same person. Another issue that affects the feasibility of the adaptation of an inverted sampling methodology to produce a large sample is the proportion of respondents who belong to various population sub-groups, in comparison to the population. Depending on the size of the desired sample, this may not be an issue; however, in situations where the members of a particular sub-group of a population are significantly underrepresented in the frame(s) relative to the proportion of the target population that belong to said subgroup, a slightly different approach must be taken.

When conducting a survey, oversampling typically involves the inclusion of the members of a particular sub-group of the target population in the sample at a greater frequency than would be the case if inclusion in the sample was solely based on the size of the subgroup relative to the population as a whole (The Pew Research Center, 2011). In machine learning, oversampling is used to reduce instances of "class imbalance" within datasets used in concept-learning problems (Jo & Japkowicz, 2004). Typically, each member of a frame used in concept-learning problems will correspond to a particular class (of varying rarity or complexity), with the number of entries that correspond to a particular class decreasing as the complexity of said class increases. In this type of problem, oversampling entails the random duplication of entries that correspond to particular classes in order to ensure a balance among the varying classes (in terms of frequency) (Jo & Japkowicz, 2004). This method could be incorporated into an inverted-sampling methodology to ensure that sub-groups that are under-represented in the source frames are proportionally represented (relative to the target population) in the final sample, however this may result in a reliance on a small number of entries which themselves may not adequately reflect various demographic traits of the sub-group as a whole.

Under-sampling, a similar method that entails the random deletion of entries in order to achieve class balance (Jo & Japkowicz, 2004), could also be applied to match the proportional representation of a particular sub-group in the source frames to the proportional representation of the same group within the target population. This, however, has the potential to reduce the degree to which the data reflects the various demographic qualities of the sub-groups whose entries have been removed. Another option is to both oversample the entries of those who belong to certain sub-groups and under-sample the entries of those who belong to other sun-groups. Jo and Japkowicz (2004) find this to be a more effective approach than either method alone,

from the perspective of the performance of classification algorithms. Regardless of whether oversampling, under-sampling, or a combination of both are incorporated into an inverted sampling methodology, it cannot be truly effective if any sub-group is not included in the source frame(s).

However, even with the above corrective measures, the coverage of this approach is not certain. The completeness of the combined frame via inverted- sampling, therefore, needs to be investigated. The completeness of each alternative frames directly impacts the quality of the inverted-sampling technique. If employers and post-secondary institutions are unwilling to participate in the survey, then the reserve sampling overall frame would not only be incomplete but extremely biased. A prior willingness survey is required to investigate the participation rate of the businesses and schools in the GGH region to evaluate the feasibility of this approach. This is proposed to be explored in a subsequent field test during the next phase of the TTS 2.0 project.

10 SUMMARY, RECOMMENDATIONS AND FUTURE WORK

This report conducted an intensive, but not exhaustive, study on different sampling frames, comparing the advantages and limitations of each frame towards suggesting an "ideal" alternative frame fora proposed TTS 2.0 data collection program. Section 2 looked at the deficiencies of landline-based frames experienced in past surveys in both Canada and worldwide. Varying conclusions were found in the literature regarding the issues in landline telephone frames; a 2001 epidemiological survey in Canada suggested no significant difference in response demographics with respect to gender and age, while others indicated that landline frames were more likely to have respondents who are white middle-aged females. These inconsistent conclusions were followed up in Section 3, where the demographics of past TTS surveys were compared with the demographics of the Canadian census to identify bias within GGH. A clear trend in increasing bias was found when comparing the age group representations within the region between the 2006 and 2011 TTS results. The young adult population was severely under-represented in the 2006 survey, and the situation worsened in 2011, where less than a quarter of the census tracts properly represented the young adult population adequately. The senior population, on the contrary, was significantly over-represented, especially in the downtown regions. However, no significant bias was observed with respect to gender. The analysis confirmed the inadequacy of the current landline frame for the TTS, leading to an examination of alternatives in Sections 4 to 8.

Section 4 looked specifically at mail frames. It was found that the coverage for the mail frame within the GGH was complete, and available through Canada Post and Info Canada. The response rate was a huge concern from many survey researchers; it was found that monetary incentives after the initial contact mail, follow up through the mail, and pre-notification letters increased response rate significantly. Analyzing demographics, older middle classed females with higher education have been found to be more likely to respond to mail surveys. However, there were limited studies targeting the GGH area, and demographics have been noted to vary according to the region. Therefore, the following field tests could be implemented to investigate the feasibility of mail frames for the TTS:

- Conduct a small targeted mail survey with an address based list frame to determine the actual response rate of mail surveys in the urban area. This information might also be obtained from an analysis of the 2016 TTS survey data.
- Conduct a mail-based field test with two rounds, each with different amounts and types of incentives (cash vs lottery). In the first round of field test, incentives should be sent out with the initial mailing, while for the second round of field test, incentives should be only provided in the follow-up mail for those who did not respond.

However, given the reluctance of the TTS to provide incentives both due to cost and to avoid introducing bias, the second field test may not be of value.

Section 5 focused on probability-based web panels and email list frames. In conclusion, email list frames are only viable for satellite surveys because of the inaccessibility of the frame, and the lacking of existing complete email lists. On the other hand, probability-based web panels were found to have similar demographics to the overall population according to varies studies around the world, but the demographics of popular Canadian web panels are very similar to landline and mail frames, with lower response rates than their international counterparts.

Section 6 looked at the increasingly popular approach of mixed-mode surveys and mixed sample frames. It presented research that considered questions of whether additional data collection modes would increase the response rate, whether it would reduce non-response bias, and what would be the costs of combining multiple

methods. It was discovered that increasing the number of data collection modes does increase response rate; however, this increase did not contribute to reducing non-response error because it does not account for coverage bias. The measurement error existing among different modes also hindered the data quality. The difference was more significant between interviewer-assisted survey modes and self-interviewed survey modes. The following field test is recommended to test the feasibility of mail/the web mixed mode survey which was utilized by the Canadian census.

- Conduct a mail/web mixed survey to compare the non-response error and response rate to mail surveys for measurement error.

Section 7 took a deeper look into cell phone and landline dual frames, elaborating on what was found in the prior 2015 report with more cases and scenarios. The dual frame was found to be an efficient way to increase representation of underrepresented demographics in traditional landline frames (specifically men between the ages of 18 and 34). The inclusion of a cell phone frame would also expand coverage of the original frame to correct the issue of non-response bias. This frame is widely used in the United States. The major issued found in the section was the limitation of an available cell phone frame source in Canada and the cost of the frames. The price per cell phone number provided by ASDS is around $4 (ASDS, 2016) and, therefore, the following field test, tailored to GGH region, is recommended:

- A survey utilizing a dual frame to get the demographics, response rates and costs in the GGH (or alternatively analyze the results of the 2016 TTS which utilized a multi-frame approach).
- A voluntary survey of dual cell phone and landline users asking for the frequency of cell phone and landline usage, and how often they receive calls on each device.

Section 8 focused on the alternative frames that are generally not considered for household surveys, namely employee and post-secondary school surveys. The success of surveys of this nature in the GGH were presented, including a discussion of the potential costs of conducting surveys via these frames.

This was, finally, followed by Section 9, which introduced two possible approaches for moving forward to address the method for constructing a household frame or the way households are recruited for the TTS. The first was transitioning to a traditional multiple household frame survey with some combination of landline, cellphone and mail lists. The second, based on the use of the alternative frames presented in Section 8, was an inverted sampling method, where individuals are contacted via their place of work or study, or through member organizations. Reaching respondents through organizations introduces credibility to the survey, and may raise the response rates. However, as this is a field with minimal prior research, field tests are recommended for these topics:

- An employer and post-secondary participation survey to see how many businesses and schools are willing to participate in the TTS2.0, in order to examine the coverage of this reverse approach
- A follow-up survey to collect basic personal and household information of employees in those businesses and schools, who indicated a willingness to participate, to examine response rates, demographic coverage, and ability to recruit the entire household.

Overall, while advances have been made in the course of this report towards addressing issues in the sample frame for the TTS, additional work is needed to investigate issues where answers were not found in the literature, or to provide region-specific info about the effectiveness of certain techniques. The following rounds of field tests and further pilots in the TTS 2.0 will work to provide these answers.

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