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1 **Analyzing the Reporting Error of Public Transport Trips in the**
2 **Danish National Travel Survey Using Smart Card Data**

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1 **ABSTRACT**

2 Household travel surveys have been used for decades to collect individuals and households' travel
3 behavior. However, self-reported surveys are subject to recall bias, as respondents might struggle
4 to recall and report their activities accurately. This study examines the time reporting error of
5 public transit users in a nationwide household travel survey by matching, at the individual level,
6 five consecutive years of data from two sources, namely the Danish National Travel Survey (TU)
7 and the Danish Smart Card system (Rejsekort). Survey respondents are matched with travel cards
8 from the Rejsekort data solely based on the respondents' declared spatiotemporal travel behavior.
9 Approximately, 70% of the respondents were successfully matched with Rejsekort travel cards.
10 The findings reveal a median time reporting error of 11.34 minutes, with an Interquartile Range of
11 28.14 minutes. Furthermore, a statistical analysis was performed to explore the relationships
12 between the survey respondents' reporting error and their socio-economic and demographic
13 characteristics. The results indicate that females and respondents with a fixed schedule are in
14 general more accurate than males and respondents with a flexible schedule in reporting their times
15 of travel. Moreover, trips reported during weekdays or via the internet displayed higher accuracies
16 compared to trips reported during weekends and holidays or via telephones. This disaggregated
17 analysis provides valuable insights that could help in improving the design and analysis of travel
18 surveys, as well accounting for reporting errors/biases in travel survey-based applications.

19
20 **Keywords:** Travel Survey; Smart Card Data; Reporting Error; Public Transport; Recall Bias

1 INTRODUCTION

2 For decades, researchers and transport planners have relied on household travel surveys (HTS)
3 or travel diaries to collect data on the travel behavior of individuals and households. Advancements
4 in technology have brought a revolution in the domain of data collection. Particularly, passively-
5 generated big data such as GPS, mobile phone traces, and smart card (SC) data, provide
6 opportunities to complement and enrich traditional surveys (1–3) as every data collection
7 technique has advantages and drawbacks.

8 Traditional household travel surveys provide comprehensive contextual information about
9 individuals' travel behavior, travel preferences, and socio-economic characteristics and
10 additionally provide the opportunity to collect attitudinal variables that are not usually available in
11 other data sources (4). They can also be tailored by researchers to specific research objectives.
12 However, these surveys rely on the respondents' ability to accurately report details about their
13 activities such as number of trips, departure time, origin and destination, etc. Unfortunately, people
14 have a well-known tendency to inaccurately report such information (5). Researchers and transport
15 planners have long been aware of the recall bias in self-reported surveys caused by the participants'
16 inability to recall and report their travel activities accurately (6). However, a relatively fair
17 assessment of the actual margin/level of error in self-reported travel surveys has only become
18 possible with the recent implementation of GPS surveys and smart card systems (5).

19 Both GPS-based surveys and SC systems automatically collect precise and real-time data on
20 travel behavior, minimizing the reliance on individuals' memory and mitigating, although to
21 different levels, recall bias. Nonetheless, the two systems are fundamentally different. Although
22 SC systems provide only partial data on public transport passengers' travel behavior (e.g., trip
23 origin and destination are unknown), they still offer several advantages over GPS and mobile
24 phone surveys. First, SC data is not limited by equipment or battery life, allowing for longer data
25 collection periods (7). Second, the high penetration and usage rate of SC systems in many cities
26 and countries allow them to cover almost the entire population of travelers. In contrast, GPS
27 surveys may suffer from a sample selection bias, as participants who agree to participate in the
28 survey and carry a GPS device or install a smartphone app for collecting travel diaries during their
29 travel might have different behavioral and travel patterns compared to those who decline to
30 participate (8). Finally, no additional effort is required from travelers other than validating the fare
31 by tapping in and, in some cases, tapping out compared to GPS surveys where participants are
32 required to self-verify their trips (9), something that might introduce self-reporting errors in the
33 data.

34 1.1 Smart Card Data and Travel Surveys

35 Several studies have recently tried to compare and/or integrate HTS and SC data at the
36 population/aggregate level to assess the advantages and disadvantages of both data collection
37 methods and/or attempt to alleviate reporting errors in travel surveys (10). For instance, many
38 studies investigated the potential of travel underreporting in travel surveys. Ridership of the
39 Montréal, Canada, subway system was investigated by comparing an average weekday of travel
40 demand data from the 2008 Montréal HTS and one day of SC transactions from 2010 (11). Results
41 showed that the survey accurately represents daily subway ridership but overestimates subway
42 boardings during peak hours by 24%. Other studies also compared the Montréal HTS data with
43 SC data at the aggregate level. Household travel survey data from the fall of 2013 was extracted
44 to construct an average weekday data while SC data was collected on a specific day from October

1 2013 (12). The authors compared the structure of transit travel demand (e.g., spatial and temporal
2 distribution of trips) in both datasets and found that the household travel survey over-represents
3 symmetrical travel patterns observed during peak periods and between the suburbs and downtown
4 while neglecting other travel patterns. Trépanier et al. (13) found that the 5% sampling rate in the
5 household survey was insufficient for capturing significant daily temporal variations and ridership
6 of specific bus lines. Chapleau et al. (14) showed that non-home-based trips and trips made for
7 short duration activities that are mainly conducted during off-peak periods are under-reported in
8 the household travel survey. Moreover, public transit OD trip matrices were derived for Lyon,
9 France, from a household travel survey, a large-scale OD survey, and an entry-only smart card
10 data (15). Results showed that although the three matrices share some similarities, they have
11 significant differences that must be acknowledged and investigated. For instance, the household
12 travel survey tends to underestimate public transport trips by approximately 30% while
13 overestimating long-distance and multi-leg trips during peak hours.

14 While most of the previous studies have compared travel surveys and smart card data at the
15 population/aggregate level, very few efforts have been made to match and compare the two data
16 collection methods at the individual level (7, 10, 16). Riegel and Attanucci (16) compared SC
17 transactions with London Travel Demand Survey (LTDS) responses of individuals who willingly
18 provided their smart card numbers to enable their identification in the smart card data. Only around
19 half of the reported trip legs over a 9-month period were matched to SC transactions. In addition,
20 large differences in duration and start time were noticed with an average start time difference of
21 more than an hour. Spurr et al. (7) applied a methodology based on spatiotemporal filters to match
22 SC data with HTS responses of individuals who were not asked to provide their smart card
23 numbers. The authors were able to match roughly 50% of HTS transit users and identify as such
24 three different categories of survey respondents: those who report almost accurately their travel,
25 those who underreport their travel, and those who report typical trips instead of actual ones.
26 However, the study is limited to one day of travel diaries from the 2013 Montréal HTS and as such
27 the derived typology is not exhaustive. Su et al. (10) compared self-reported travel data from the
28 MIT commuting survey with SC transactions and on-campus parking records of MIT employees
29 both at the aggregated and individual level. Results showed some level of inconsistency between
30 the datasets and that the overreporting and underreporting of commuting patterns are associated
31 with certain individual characteristics such as age and employment type. However, the study is
32 limited to a particular category of the population (MIT employees). In addition, the datasets were
33 not matched on a daily basis nor daily discrepancies were assessed.

34 In summary, previous studies have mostly compared HTS data and SC transactions at the
35 aggregate level, while those few who delved into a more detailed comparison at the disaggregate
36 level were often limited by time constraints such as one day of data, a few months, or data from
37 different time periods for each dataset. Consequently, there is a lack of exhaustive and
38 comprehensive comparison between the two different data collection methods at the individual
39 level, specifically in quantifying reporting errors in travel surveys and their correlation with socio-
40 economic and demographic characteristics. This paper aims to fill this gap as it tries to match 5
41 consecutive years (2018 to 2022) of smart card data and household travel survey for the entirety
42 of Denmark with the objective of quantifying the reporting error of public transport users in the
43 Danish national travel survey and investigating the relationships between these errors and various
44 socio-economic characteristics of travelers. Such analysis should yield valuable insights that can
45 help in improving the design and analysis of travel surveys, leading to more accurate data
46 collection techniques. It would also help researchers in accounting for reporting errors/biases when

1 using travel survey data. Furthermore, it would offer valuable insights underlying the psychology
2 of travel recall by survey respondents. To the best of our knowledge, this is the largest and most
3 in-depth analysis of this sort thanks to the sheer size of the datasets used and the unique
4 characteristics of the Danish national travel survey.

5 **2 DATA**

6 This section describes the two datasets used in this study, the smart card Rejsekort data and
7 the Danish National Travel Survey (TU Data).

8 **2.1 Smart Card - Rejsekort - Data**

9 The Danish Rejsekort (travel card in English) is the nationwide SC system for traveling by
10 public transport in Denmark. Under this system, passengers must tap-in at their origins and transfer
11 locations and tap-out at their destinations. The Rejsekort system covers all public transport modes
12 (buses, metros, and trains), transport operators, and travel zones in Denmark (17). Each Rejsekort
13 transaction stores information on the type of transaction (tap-in, transfer, or tap-out), time and
14 location of the transaction, type of the card, and fake card ID (Rejsekort IDs are pseudo-
15 anonymized for privacy concerns). For this study, the whole Rejsekort data for all Denmark from
16 2018 to 2022 are used.

17 **2.2 Danish National Travel Survey - TU Data**

18 The Danish National Travel Survey (or Transportvaneundersøgelsen, TU) is an annual
19 survey that aims to capture travel diaries of a representative sample of the Danish population aged
20 6 years and above (18). The survey is conducted on random days throughout the year and is either
21 answered via telephone (80%) or internet (20%). Participants are asked to provide detailed
22 descriptions of all their trips undertaken using both private and public modes of transportation on
23 the day prior to the interview in addition to their own and households' socio-economic
24 characteristics. For this study, public transport trips conducted with a Rejsekort card between 2018
25 and 2022 are selected for matching with trips from the Rejsekort data during the same period. The
26 collected information on public transport trips is sufficiently detailed to enable matching the
27 reported trips with the "actual" trips recorded in the Rejsekort data. For each public transport trip
28 in the TU survey, respondents are asked to provide start and end times, all modes (train, bus, metro)
29 used for all legs of the trip, waiting time, bus line, length and travel time for each mode and leg,
30 names of boarding, transfer, and alighting metro and train stations, etc. Table 1 summarizes the
31 number of public transport users and trips reported as conducted by a Rejsekort card in the TU
32 data between 2018 and 2022. We only try to match TU respondents who reported two or three
33 trips per day with corresponding cards from the Rejsekort data. This is based on the understanding
34 that the likelihood of finding multiple individuals/cards with exactly the same two or three trips
35 per day (same tap-in and tap-out locations and times) is expected to be very low. On the other
36 hand, for TU respondents who reported only one trip per day, there is a higher probability of
37 identifying multiple matches in the Rejsekort data, where cards have transactions with the same
38 tap-in and tap-out locations and times. In total, 3,750 public transport trips were reported by 2,116
39 respondents as made using a Rejsekort card between 2018 and 2022. Out of those, 1,208
40 respondents reported two trips per day while only 128 respondents reported three trips per day.
41 Therefore, the total number of respondents used for matching is 1,336 which corresponds to 2,800
42 trips (Table 1).

1 **Table 1: Public transport trips and Rejsekort users in TU data from 2018 to 2022**

Year	Reported PT Trips	Respondents with PT Trips	Respondents with 1 PT trip/day	Respondents with 2 PT trips/day	Respondents with 3 PT trips/day	Respondents with 4+ PT trips/day
2018	732	427	169	223	24	11
2019	786	442	150	255	28	9
2020	681	388	141	216	19	12
2021	664	374	125	218	24	7
2022	887	485	144	296	33	12
Total	3,750	2,116	729	1,208	128	51

2 **3 MATCHING**

3 For the purpose of matching reported TU trips with Rejsekort trips, we classify the
4 respondents from the TU data into three categories - train, bus, and mixed users - and perform the
5 matching for each category separately. The train users are respondents who reported 2 or 3 trips
6 where all legs of all trips were made by train or metro. The bus users are respondents who reported
7 2 or 3 trips where all legs of all trips were made by bus. Mixed users are respondents who reported
8 2 or 3 trips of mixed bus and train legs.

9 In order to develop a matching process between the two datasets, it is necessary to understand
10 the definition and characteristics of a trip category in each dataset. Figure 1 shows the definition
11 and attributes of a train trip as described in both datasets. Actual origin and destination are not
12 known in the TU dataset for privacy concerns. However, all time instants (e.g., departure and
13 arrival times) of a train trip from origin to destination are known as well as the names of the
14 boarding, transfer, and alighting stations. As for the Rejsekort data, origin and departure times are
15 not known and neither are the destination and arrival times. Instead, only names and times, precise
16 to the nearest second, of tap-in and tap-out stations are known. A traveler taking a train can tap-in
17 any time between arrival at the station and right before boarding the train. However, it is assumed
18 that travelers usually tap-in when arriving at the station. Therefore, we define the reported arrival
19 time to the first station in the TU data as the possible tap-in time. As for tap-out time, it corresponds
20 to alighting time of the last train as travelers usually tap-out right after leaving the train.

21 Given that TU respondents are not asked to provide their Rejsekort IDs and the IDs in the Rejsekort
22 dataset are themselves pseudo-anonymized, matching respondents in the TU data to smart cards
23 from the Rejsekort data can only be performed based on their observed travel behaviors. The
24 matching methodology for the train category is described as follows:

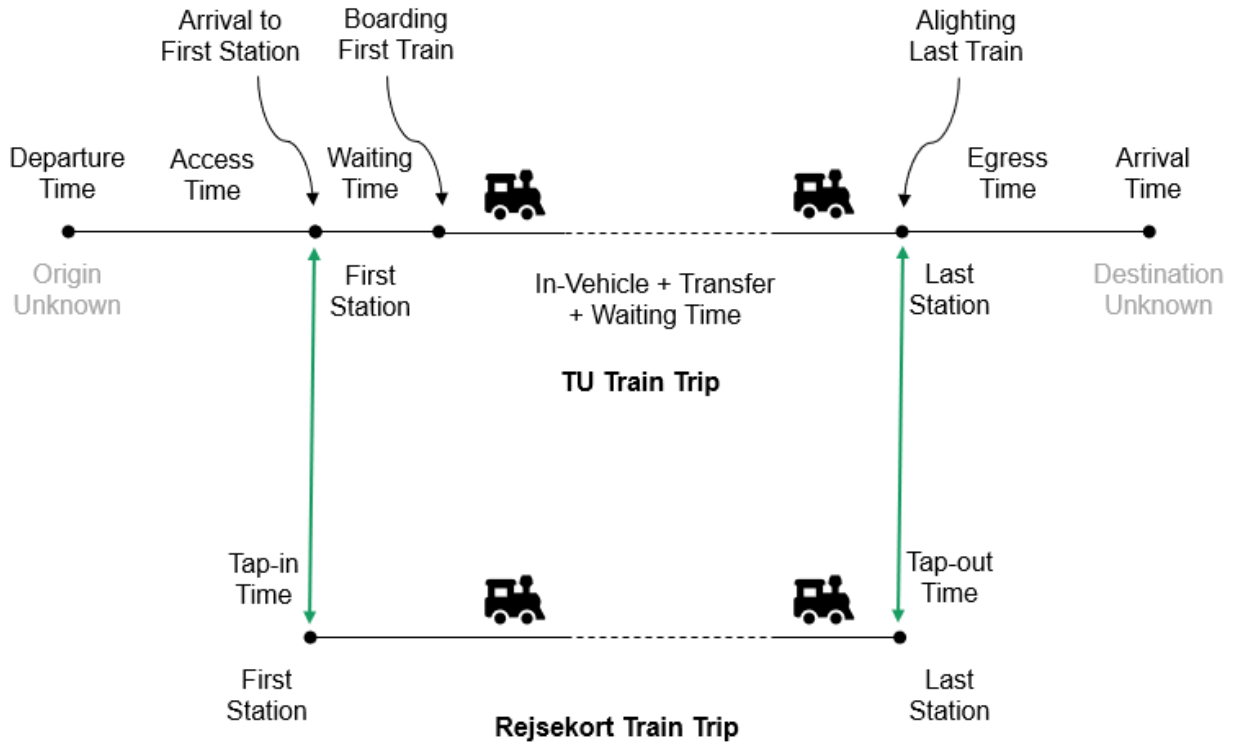
- 25 1. Given an individual n who reported in the TU survey $I_n: \{2,3\}$ trips by train during a
26 specific day d , get the names of the first (boarding) and last (alighting) stations of each trip
27 $i \in I_n$ from TU data
- 28 2. Find I_n trips in the Rejsekort data made by the same Rejsekort card that match the names
29 of the stations from the TU data during day d

- 1 3. Compute absolute time difference, ΔT_n , between Tap-in/Tap-out times from Rejsekort data
 2 and Arrival to first/last stations from TU data of all trips as follows:

3
$$\Delta T_n = \sum_{i=1}^{I_n} \Delta T_{n,First_St_i} + \sum_{i=1}^{I_n} \Delta T_{n,Last_St_i}$$

4 where $\Delta T_{n,First_St_i}$ is the absolute time difference of trip i between arrival time to first
 5 station from TU data and tap-in time at first station from Rejsekort data; $\Delta T_{n,Last_St_i}$ is the
 6 absolute time difference of trip i between alighting time at last station from TU data and
 7 tap-out time at last station from the Rejsekort data.

- 8 4. If there is more than one match, select the one with the smallest ΔT_n
 9

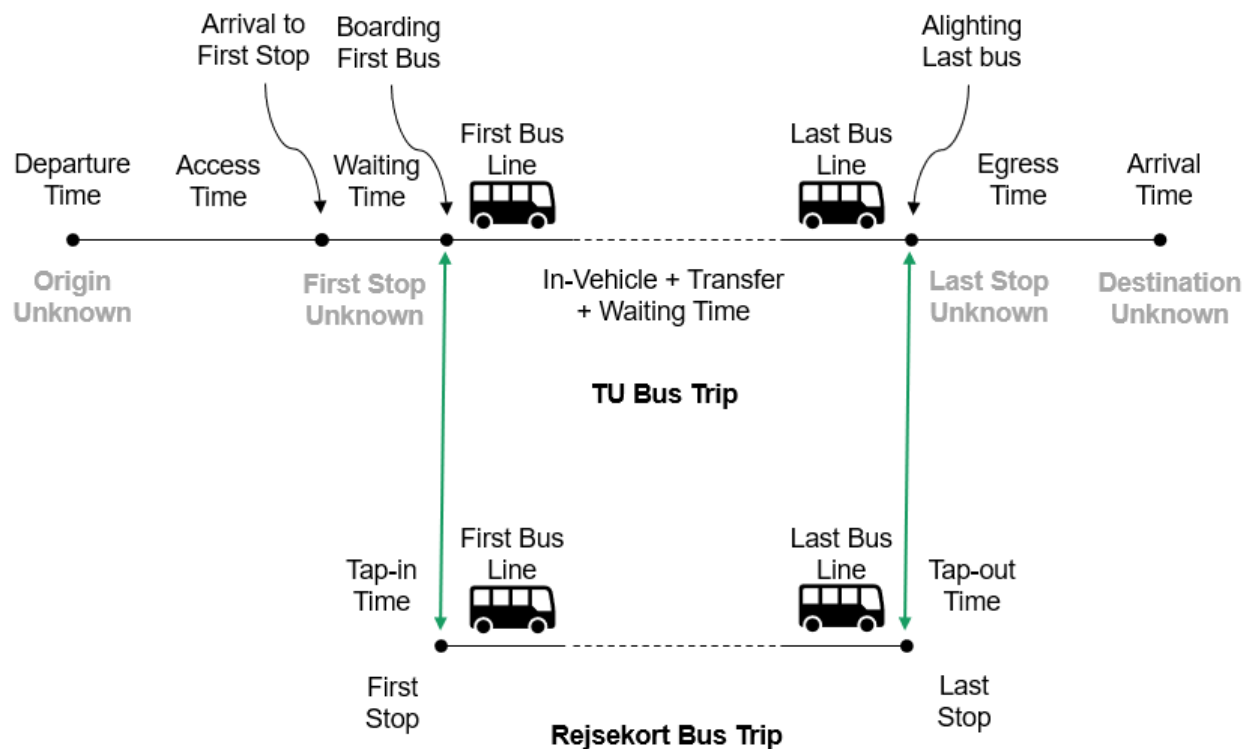


10

11 **Figure 1: Train trip attributes as recorded by TU and Rejsekort data**

12 Similarly to a train trip, the actual origin and destination of a bus trip are not observed in the
 13 TU dataset for privacy concerns. In addition, names of boarding and alighting bus stops are not
 14 recorded. Instead, respondents are asked about the boarding and alighting bus lines. As for the
 15 Rejsekort data, both bus lines and bus stops are recorded (Figure 2). Therefore, the matching
 16 process for the bus category is based on the bus lines instead of bus stops and follows the same
 17 steps previously mentioned for the train trips as follows: 1) get the names of bus lines at the first
 18 (boarding) and last (alighting) stops instead of names of bus stops; 2) find trips in the Rejsekort
 19 data made by the same Rejsekort card that match the names of the bus lines; 3) compute the
 20 absolute time difference ΔT_n where $\Delta T_{n,First_St_i} / \Delta T_{n,Last_St_i}$ are the absolute time difference
 21 between boarding time of first bus / alighting time of last bus from TU data and tap-in time at first

- 1 stop / tap-out time at last stop from Rejsekort data; 4) if there is more than one match, select the
- 2 one with the smallest ΔT_n .



3

4 **Figure 2: Bus trip attributes as recorded by TU and Rejsekort data**

4

5 Finally, the matching of the mixed category is based on a combination of the train (stations)

6 and bus (lines) matching processes.

7 4 RESULTS & STATISTICAL ANALYSIS

7

8 This section presents the results of the matching process between the two datasets in addition

9 to a statistical analysis.

10 4.1 Matched Sample

10

11 Around 70% of TU respondents with 2 or 3 PT trips were successfully matched with at least

12 one Rejsekort card with equivalent sequences of tap-ins/tap-outs (Table 2). The matched

13 respondents can be divided into the following categories: 507 respondents (53.82%) with train

14 trips, 304 (32.27%) with bus trips, and 131 (13.91%) with mixed trips. In addition, 898 matched

15 respondents (95.33%) reported 2 trips while only 44 matched respondents (4.67%) reported 3 trips.

16 Therefore, the total number of matched trips is 1,928. Unmatched trips can be attributed to several

17 potential factors such as people reporting incorrect train/metro stations or bus lines, potential data

18 entry mistakes by interviewers, people forgetting to tap-out at the alighting station/stop, etc.

1

Table 2: Matching results

Year	TU Respondents with 2 or 3 PT trips	Matched TU respondents with specific Rejsekort cards	Matching %
2018	247	169	68.42%
2019	283	217	76.68%
2020	235	165	70.21%
2021	242	176	72.73%
2022	329	215	65.35%
Total	1,336	942	70.51%

2 A Shapiro test was applied to several time difference variables (ΔT_n , average ΔT_n ,
3 $\Delta T_{n,First_St}$) to assess the normality of the data. None of the variables are normally distributed at a
4 99% level of confidence ($p < 0.01$), indicating that non-parametric tests should be used for
5 statistical analysis. The dependent variable of interest for the statistical analysis is the time
6 difference at the first stop/station $\Delta T_{n,First_St}$. We also call it time reporting error of respondents
7 in the TU survey or start time difference.

8 The reporting error of the matched trips varies between 0 and around 8 hours with a mean
9 of 33.87 minutes and a standard deviation of 65.12 minutes. While these values are relatively high,
10 they are still 50% lower than those from (16) who reported a mean of 61.2 minutes, a standard
11 deviation of 151.7 minutes and start time differences ranging from 0 to 15 hours. It is highly
12 unlikely that a respondent misreported their departure time by 8 hours. Therefore, to lessen the
13 impact of outliers and given that the data is not normally distributed but instead is positively
14 skewed (Figure 3), relying on the median and quartiles would provide a more accurate
15 representation of the data. The reporting error has a median of 11.34 minutes and an Interquartile
16 Range (IQR¹) of 28.14 minutes. Given that the temporal resolution in the TU survey is 5 minutes²,
17 a median reporting error that is more than twice the temporal resolution cannot be ignored or solely
18 attributed to the 5-minute discretization in the TU survey. Several studies have documented that
19 most respondents tend to round their departure times to multiples of 5, 15, and 30 minutes (5).
20 Such large rounding scales could introduce biases into any analysis based on national travel
21 surveys, particularly when probabilities of rounding upward and downward do not balance out
22 (19).

¹ IQR is the difference between the third (75th percentile) and first (25th percentile) quartiles ($Q_3 - Q_1$). It measures the spread of the middle 50% of the data. It is robust against outliers and an alternative to the standard deviation in case of extreme values.

² When selecting time in the TU survey, respondents can choose from a list of 5-minute bins (e.g., 9:05, 9:10 etc.)

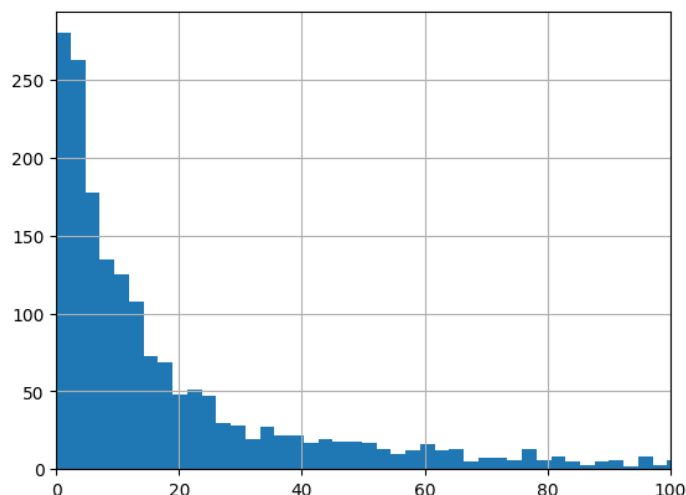


Figure 3: Distribution of the time difference at the first stop/station $\Delta T_{n,First_St}$ (in minutes)

4.2 Statistical Analysis

Several non-parametric tests are used to compare the dependent variable of interest against different socio-economic variables and their levels. First, the Mann-Whitney U-Test, a non-parametric statistical alternative to the two-sample t-test, is used to compare two independent groups. Second, the Kruskal-Wallis H test, a non-parametric statistical alternative to the one-way ANOVA, is used to compare the distribution of more than two independent samples. Finally, the Wilcoxon Signed Rank test, a non-parametric alternative to the paired samples t-test, is used to compare two dependent samples.

4.2.1 Two-level variables

In this section, differences between different groups of the population are investigated using the Mann-Whitney U-Test. Descriptive statistics for each group in addition to the p-values of the Mann-Whitney U-test are presented in Table 3. Results show that there are statistical differences at either the 99% or 95% level of confidence between the categories of all the variables. There are statistical differences between males and females at the 99% level of confidence with a higher median value for males (13.33 minutes) compared to females (10.17 minutes), indicating that females are in general more accurate than males in reporting their time of travel. This is in line with insights from the field of psychology that women usually perform better than men on episodic memory³ tasks (20). A statistically significant difference in the medians of the two categories of Day Type 1 is found at the 95% level of confidence, suggesting that people are more accurate in reporting their time of travel during weekdays (11 minutes) than during weekends (13.23 minutes). More specifically, people are more accurate in reporting their time of travel during normal weekdays than during weekends and weekdays with holidays (Day Type 2). This is intuitive and expected as people usually follow a predictable routine during the week (e.g., going to work or school), which makes it easier for them to recall and report their time of travel accurately. In contrast, weekends and holidays usually involve a less structured routine with a wider range of nonrepetitive activities (e.g., leisure and social activities), which can make it more

³ Episodic memory is the ability to recall past events or experiences at particular times and spaces.

1 challenging for respondents to remember and accurately report their time of travel. Moreover, we
2 categorize respondents according to their schedule flexibility into two groups: those with fixed
3 schedules (e.g., students, employees) and those with flexible schedules (e.g., unemployed,
4 pensioner). A statistically significant difference between the medians of the two groups is evident
5 at the 99% level of confidence. Specifically, respondents with flexible schedules (14.59 minutes)
6 are less accurate in reporting their time of travel in comparison to respondents with fixed schedules
7 (10.78 minutes). This further supports the previous finding that people on average are more
8 accurate during weekdays than during weekends and holidays, which tend to involve greater
9 schedule flexibility. A statistically significant difference at the 99% level of confidence is also
10 observed for interview type, with internet-based responses having a much lower median (7.23
11 minutes) than telephone-based responses (12.72 minutes). Internet-based surveys usually
12 incorporate visual aids (e.g., maps or timelines), which assist respondents in remembering and
13 reporting their time of travel. Furthermore, internet-based surveys provide respondents with the
14 flexibility to answer at their own pace and convenience, allowing them more time to recall and
15 report their answers without feeling rushed or distracted/interrupted as they might in telephone-
16 based surveys. Moreover, the elimination of interviewers in internet-based surveys has been shown
17 to minimize social desirability bias (21) and thus lead to higher reporting accuracy. Finally, trips
18 are divided into two categories, Jutland and Zealand/Funen, according to the location of their
19 origins and destinations. A statistically significant difference at the 99% level of confidence is
20 evident between the median values of the two geographical locations with trips conducted in
21 Jutland having a much lower median value (7.63 minutes) than those conducted in Zealand and
22 Funen (12.31 minutes). Note that Zealand is the most populous island in Denmark and includes
23 the capital Copenhagen. Zealand, and to some extent Funen, are characterized by urban and fast-
24 paced environments while Jutland is predominantly rural. As such, Jutland experiences, in general,
25 a lower bus frequency compared to Jutland, while metro is only available in Copenhagen. This
26 could explain the finding that people in Jultand are more accurate than those from Zealand and
27 Funen as with lower bus frequencies travelers might be more aware of the bus schedules to
28 minimize waiting times.

29 A sensitivity analysis was also performed to test whether the Mann-Whitney U-Test
30 conclusions hold if trips with high reporting errors are excluded. The statistical analysis was thus
31 repeated using different cut-off points at 200, 100, 60, and 30 minutes, respectively. The outcomes
32 of the sensitivity analysis are presented in Table 4 and show the robustness of the Mann-Whitney
33 U-Test results. Differences between males and females and day types (1 and 2) are statistically
34 significant at all cut-off points except 30 mins with higher median values for males compared to
35 females and for weekends & holidays compared to weekdays regardless of the cut-off point. As
36 for interview type, schedule flexibility, and location, statistically significant differences are
37 observed at all cut-off points with higher median values for telephone-based surveys, flexible
38 schedules, and Zealand/Funen compared to internet-based surveys, fixed schedules, and Jutland,
39 respectively.

40

1

Table 3: Descriptive statistics (in minutes) and Mann-Whitney U-Test

		Count	Mean	Std	25%	50% - Median	75%	IQR
Gender	Male	856	37.09	64.10	4.68	13.33	41.71	37.03
	Female	1,072	31.30	65.85	3.75	10.17	25.39	21.64
						0.000***		
Day Type 1	Weekdays	1,623	33.38	64.58	3.83	11.00	31.57	27.73
	Weekends	305	36.49	68.00	5.72	13.23	37.15	31.43
						0.015**		
Day Type 2	Weekdays	1,502	32.11	62.83	3.82	10.78	29.67	25.85
	Weekends & Holidays	426	40.09	72.39	5.61	13.61	40.63	35.02
						0.000***		
Interview Type ⁴	Internet	424	22.85	48.96	2.85	7.23	18.33	15.48
	Telephone	1,441	37.14	69.06	4.68	12.72	36.60	31.92
						0.000***		
Schedule Flexibility	Fixed	1,447	33.28	67.00	3.88	10.78	28.92	25.03
	Flexible	418	35.37	59.141	4.55	14.59	39.65	35.10
						0.002***		
Location ⁵	Zealand & Funen	1,610	35.42	66.62	4.52	12.31	34.63	30.10
	Jutland	318	26.06	56.43	2.95	7.63	21.19	18.24
						0.000***		

2

** significance at the 95% level of confidence

3

*** significance at the 99% level of confidence

⁴ Very few interviews are labeled as reconstructed or combined interviews instead of internet or telephone interviews and as such are not included in the analysis.

⁵ Zealand, Funen, and Jutland are the three main islands in Denmark. Zealand is the most populous island in Denmark and includes the capital Copenhagen.

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Table 4: Sensitivity analysis of the Mann-Whitney U-Test w.r.t different cut-off points

		Cut-off point									
		All data		200 mins		100 mins		60 mins		30 mins	
		Count	Median	Count	Median	Count	Median	Count	Median	Count	Median
Gender	Male	856	13.33	804	12.00	720	10.63	622	8.63	463	6.47
	Female	1,072	10.17	1,006	9.23	950	8.44	880	7.84	708	6.29
	P-value		0.000***		0.000***		0.000***		0.028**		0.353
Day Type 1	Weekdays	1,623	11.00	1,522	10.01	1,407	8.83	1,276	7.78	1,006	6.18
	Weekends	305	13.23	288	12.39	263	11.07	226	10.12	165	7.38
	P-value		0.015**		0.002***		0.004***		0.026**		0.139
Day Type 2	Weekdays	1,502	10.78	1,414	9.85	1,309	8.83	1,194	7.83	945	6.18
	Weekends & Holidays	426	13.61	396	12.63	361	11.07	308	9.33	226	6.96
	P-value		0.000***		0.001***		0.002***		0.042**		0.196
Interview Type	Internet	424	7.23	409	7.03	387	6.33	352	5.63	320	5.04
	Telephone	1,441	12.72	1,344	11.63	1,228	10.27	1,103	9.20	813	6.88
	P-value		0.000***		0.000***		0.000***		0.000***		0.000***
Schedule Flexibility	Fixed	1,447	10.78	1,361	9.97	1,257	8.72	1,142	7.82	918	6.35
	Flexible	418	14.59	449	13.15	413	11.58	360	9.608	253	6.52
	P-value		0.002***		0.001***		0.000***		0.021**		0.058*
Location	Zealand & Funen	1,610	12.31	1,507	11.08	1,390	10.13	1,237	8.72	940	6.63
	Jutland	318	7.63	303	7.40	280	6.70	265	6.25	231	5.17
	P-value		0.000***		0.000***		0.000***		0.000***		0.009***

3 * significance at the 90% level of confidence
 4 ** significance at the 95% level of confidence
 5 *** significance at the 99% level of confidence

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1 4.2.2 *Three-level+ variables*

2 A comparison between the three trip categories (train, bus, and mixed), different years from
3 2018 to 2022, and the different positions of respondents within their families is conducted using
4 the Kruskal-Wallis H test (Table 5). First, the Kruskal-Wallis H test shows a statistically
5 significant difference between the three trip modes (train, bus, and mixed) at the 99% level of
6 confidence. The results also show that respondents reporting only train/metro trips are the least
7 accurate in reporting their time of travel (12.70 minutes) while respondents reporting only bus trips
8 are the most accurate (9.69 minutes). This discrepancy could be attributed to the higher frequencies
9 of trains and metros, leading travelers to be more aware of bus schedules to minimize waiting
10 times. Second, there are no statistically significant differences in the reporting error across the
11 years from 2018 to 2022. Nevertheless, there is a consistent downward trend in the median value
12 of the reporting error over the years, decreasing from 14.68 minutes in 2018 to 10.12 minutes in
13 2022. It is worth noting that the Rejsekort system underwent initial testing on a limited scale in
14 2007, but it was not until mid-2016 that it was implemented nationwide. This could potentially
15 explain the higher median value observed in 2018, as the system was still relatively new, and
16 people may not have been fully accustomed to it. Finally, a statistically significant difference
17 between the different positions of respondents in their families is evident at the 99% level of
18 confidence. Single respondents are the least accurate with a median value of 13.33 minutes while
19 respondents categorized as “younger in couple” are the most reliable in reporting their time of
20 travel with a median value of 9.28 minutes. It is worth noting that around 81% of the respondents
21 under the “younger in couple” category are females while around 78% of the “older in couple”
22 respondents are males. This further supports the finding that “younger in couple” respondents are
23 more accurate than “older in couple” respondents and is aligned with the results from the previous
24 section (4.2.1), which indicated that females are in general more accurate than males.

25 A sensitivity analysis was also conducted with different cut-off points as done earlier in
26 Section 4.2.1. The results presented in Table 6 confirm the findings of the Kruskal-Wallis H test.
27 Statistically significant differences between the train, bus, and mixed travel modes are observed
28 across all cut-off points. The bus category consistently displays the lowest median values while
29 the train category consistently displays the highest median values. Furthermore, differences over
30 the years are consistently not statistically significant across all cut-off points. As for the position
31 in family, the statistical significance of the differences holds true until the 100-minute cut-off
32 point.

33 4.2.3 *1st vs. 2nd trip*

34 This section focuses on investigating the effect of reporting multiple trips on the
35 respondents’ memory. Specifically, respondents who reported 2 trips are selected for analysis. The
36 Wilcoxon Signed Rank test is applied to test for statistical differences between reporting the first
37 and second trip of the day. Descriptive statistics of the dependent variable, the resulting p-value of
38 the test, and outcomes of the sensitivity analysis are presented in Table 7. A statistically significant
39 difference at the 99% level of confidence between the medians of the first and second trips is
40 identified. The second trip exhibits a higher median value of 12.64 minutes compared to 10.23
41 minutes for the first trip suggesting that people are more accurate in reporting the start time of the
42 first trip of the day. This could be explained by the primacy effect concept which has been widely
43 studied in psychology and sociology. The primacy effect is a cognitive bias that refers to the
44 tendency of people to better recall items or events that occurred or were presented at the beginning

- 1 of a series or sequence (22). The sensitivity analysis confirms the robustness of the aforementioned
- 2 finding as statistically significant differences are observed at the 99% level of confidence with
- 3 higher median values for the second trip over all cut-off points.

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Table 5: Descriptive statistics and Kruskal-Wallis H test

		Count	Mean	Std	25%	50% - Median	75%	IQR
Mode	Train	1,029	34.26	63.54	4.65	12.70	36.60	31.95
	Bus	622	33.08	66.21	3.77	9.69	26.60	22.84
	Mixed	277	34.21	68.63	3.93	10.50	24.10	20.17
	P-value					0.006***		
Year	2018	347	38.58	68.47	4.78	14.68	40.38	35.60
	2019	444	34.91	67.90	4.38	12.00	29.27	24.89
	2020	336	34.64	72.04	3.78	11.22	31.74	27.97
	2021	362	28.01	51.63	4.19	11.28	24.99	20.80
	2022	439	33.35	63.86	3.78	10.12	30.44	26.66
	P-value					0.161		
Position in family	Single	659	40.48	75.97	4.58	13.33	39.03	34.45
	Older in Couple	391	31.04	59.21	4.24	11.42	33.63	29.39
	Younger in Couple	461	26.85	51.78	3.58	9.28	24.28	20.70
	Child in family < 25 years	417	33.85	64.30	4.12	11.02	30.63	26.57
	P-value					0.003***		

2

*** significance at the 99% level of confidence

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Table 6: Sensitivity Analysis of the Kruskal-Wallis H test

		Cut-off point									
		All Data		200 mins		100 mins		60 mins		30 mins	
		Count	Median	Count	Median	Count	Median	Count	Median	Count	Median
Mode	Train	1,029	12.70	971	11.72	908	10.7	808	9.66	567	6.95
	Bus	622	9.69	582	8.85	529	7.85	482	6.92	414	5.73
	Mixed	277	10.50	257	9.22	233	7.82	212	7.32	190	6.41
	P-value		0.006***		0.002***		0.000***		0.000***		0.085*
Year	2018	347	14.68	322	11.63	296	10.73	262	9.13	180	5.88
	2019	444	12.00	410	10.63	381	9.40	345	8.15	282	6.81
	2020	336	11.22	314	9.58	296	8.90	263	7.83	205	5.60
	2021	362	11.28	347	11.00	321	10.05	293	8.85	232	6.97
	2022	439	10.12	417	9.68	376	8.29	339	7.43	272	6.31
	P-value		0.161		0.285		0.11		0.15		0.35
Position in Family	Single	659	13.33	602	12.00	550	10.41	500	9.67	373	6.95
	Older in Couple	391	11.42	377	10.85	353	9.68	303	8.15	232	6.29
	Younger in Couple	461	9.28	439	8.83	409	7.82	387	6.98	317	6.00
	Child < 25 years	417	11.02	392	10.35	358	8.92	312	7.51	249	6.45
	P-value		0.003***		0.029**		0.025**		0.112		0.658

- 2 * significance at the 90% level of confidence
- 3 ** significance at the 95% level of confidence
- 4 *** significance at the 99% level of confidence

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Table 7: Descriptive statistics, Wilcoxon Signed Rank test, and sensitivity analysis

	Count	Mean	Std	25%	50% - Median	75%	IQR
All data							
1 st Trip	898	32.11	64.42	3.78	10.23	30.99	27.22
2 nd Trip	898	35.88	66.03	4.57	12.64	34.31	29.74
P-value					0.002***		
Cut-off point – 200 mins							
1 st Trip	842				9.38		
2 nd Trip	842				11.60		
P-value					0.003***		
Cut-off point – 100 mins							
1 st Trip	781				8.37		
2 nd Trip	781				10.28		
P-value					0.007***		
Cut-off point – 60 mins							
1 st Trip	703				7.08		
2 nd Trip	703				9.23		
P-value					0.002***		
Cut-off point – 30 mins							
1 st Trip	551				5.63		
2 nd Trip	551				7.40		
P-value					0.001***		

2

*** significance at the 99% level of confidence

1 **5 CONCLUSION**

2 This paper quantified the time reporting error of public transit users in a nationwide
3 household travel survey by matching five years of data from two sources, the Danish National
4 Travel Survey (TU) and the Danish Smart Card system (Rejsekort). Around 70% of TU
5 respondents who reported 2 or 3 public transport trips were successfully matched with travel cards
6 from the Rejsekort data solely based on respondents' declared travel behavior and tap-in/tap-out
7 transactions. The reporting error had a median of 11.34 minutes with an Interquartile Range of
8 28.14 minutes. In addition, the paper investigated the relationships between the survey
9 respondents' reporting error and their socio-economic and demographic characteristics using non-
10 parametric statistical tests. The results showed that males are in general less accurate than females
11 in reporting their time of travel. Respondents with a flexible schedule are also less accurate than
12 those with a fixed schedule. Moreover, trips reported during weekends and holidays, via
13 telephones, or from Zealand/Funen displayed lower accuracies compared to trips reported during
14 weekdays, via the internet, or from Jutland, respectively. Furthermore, the results showed that
15 respondents are more likely to accurately remember their time of travel by bus as opposed to train
16 or metro. The findings highlight the importance of considering individual-level comparison
17 between travel surveys and smart card data, as such comparison offers a better understanding of
18 reporting errors in travel surveys and their connections to different socio-economic and
19 demographic characteristics. It is hoped that quantifying and understanding reporting errors in
20 travel surveys could help policymakers and researchers in enhancing the accuracy and reliability
21 of such data in addition to improving data collection techniques by considering the different socio-
22 economic and demographic characteristics that have been investigated previously when designing
23 and analyzing travel surveys.

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6 **AUTHOR CONTRIBUTIONS**

7 The authors confirm contribution to the paper as follows: study conception and design: Georges
8 Sfeir, Filipe Rodrigues; data collection and software: Georges Sfeir; analysis and interpretation of
9 results: Georges Sfeir, Filipe Rodrigues, Francisco Pereira, Maya Abou Zeid; draft manuscript
10 preparation: Georges Sfeir, Filipe Rodrigues, Francisco Pereira, Maya Abou Zeid. All authors
11 reviewed the results and approved the final version of the manuscript.

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