UNIVERSITY OF TARTU
Faculty of Science and Technology
Institute of Computer Science
Computer Science Curriculum

Laura Liisa Koldekivi

Mobility Pattern Analysis using CDR: A Case Study of Estonian Public Holidays in January & February

Bachelor's Thesis (9 ECTS)

Supervisors: Rahul Goel, M.Tech.
Anto Aasa, PhD
Rajesh Sharma, PhD

Tartu 2023

Mobility Pattern Analysis using CDR: A Case Study of Estonian Public Holidays in January & February

Abstract:
With the rise of globalization and the growth of urban populations, mobility patterns have become a key factor in shaping our cities and communities. This study explores people's mobility patterns during public holidays in Estonia using Call Data Records (CDR) data. Specifically, the study investigates mobility patterns at three different location levels: top locations, home municipality, and home county. The CDR dataset used in this study contains approximately 56M records and 499K distinct callers during January and February of 2018. The results indicate a correlation between public holidays and mobility patterns at all three location levels. People are less likely to stay in their top locations on both holidays, particularly in densely populated urban cities of Estonia, such as Tallinn, Tartu, and Pärnu. Additionally, people tend to spend their holidays in another municipality, with Hiiumaa island residents exhibiting the highest mobility and Ida-Viru County showing the most significant difference in mobility between the two holidays. The study also found that on a county level, people are more likely to deviate from their usual routines on New Year's Day than on Independence Day. Overall, the results suggest that New Year's Day alters mobility patterns more than Independence Day and the average mobility. These results are beneficial for urban planning and resource allocation during the holidays.

Keywords:
CDR, Mobility Analysis, Holiday Calling Patterns, Mobility across Municipalities, Mobility across Counties

CERCS:
P170 Computer science, numerical analysis, systems, control

Liikumismustrite analüüs mobiilsideandmete põhjal: Juhtumiuuring Eesti riigipühadest jaanuaris ja veebruaris

Lühikokkuvõte:
Globaliseerumise ja linnarahvastiku kasvu tõttu on liikumismustrid saanud oluliseks teguriks meie linnade ja kogukondade kujundamisel. Järgnev töö keskendub inimeste liikumismustrite uurimisele Eesti riigipühadel ja kasutab selleks mobiiltelefonside (CDR) andmeid. Töö uurib liikumismustreid kolmel erineval tasandil: populaarsed asukohad, kodu omavalitsus ja kodu maakond. Kasutatud CDR andmestik sisaldab ca 56 miljonit kirjet ja ca 499 tuhat helistajat jaanuaris ja veebruaris 2018. aastal. Tulemused näitavad, et riigipühade ja liikumismustrite vahel on seos kõigil kolmel tasandil. Inimesed ei viibi riigipühade ajal tõenäoliselt oma populaarsetes kohtades, eriti on seda näha tihedalt asustatud linnades, näiteks Tallinn, Tartu, Pärnu. Lisaks on inimestel kalduvus tähis-

tada riigipühi teistes omavalitsustes, sealjuures Hiiumaa elanikud näitavad kõrgeimat liikuvust ja Ida-Virumaa suurimat pühade vahelist liikumiserinevust. Maakonna tasandil tulemused näitavad ka, et Uusaastal muudavad inimesed suurema tõenäosusega oma tavalist liikumisrutiini võrreldes iseseisvuspäevaga. Kokkuvõttes viitavad tulemused sellele, et Uusaasta mõjutab liikumismustreid rohkem võrreldes iseseisvuspäeva ja keskmiste tulemustega. Saadud tulemused on kasulikud linnaplaneerimise ja ressursside jaotamise jaoks riigipühade ajal.

Võtmesõnad:
CDR, mobiilsideandmed, liikumisanalüüs, riigipühade kõnemustrid, omavalitsuste vaheline liikumine, maakondade vaheline liikumine

CERCS:
P170 Arvutiteadus, arvutusmeetodid, süsteemid, juhtimine (automaatjuhtimisteooria)

Contents

1 Introduction

In recent decades, mobile phone usage has surged across all age groups worldwide, generating a massive volume of data through phone calls, messages, and internet usage. This data, known as Call Data Records (CDRs), are primarily collected by mobile phone operators for billing purposes and contain information about calls or text messages, like an ID or number for identifying the caller and receiver, the time and date of the call, and the location of the caller. However, anonymized CDR data can also be used for studying population mobility, making it an increasingly popular and accessible source of information for researchers studying various aspects of human behaviour, including population mobility during different events, such as holidays.

While holiday mobility studies are limited, [LSS$^+$22] has created an open dataset with worldwide data on public and school holidays from 2010–2019, which makes it possible to study mobility during holidays on a global scale. This growing data availability allows researchers to identify patterns and address various urban challenges during the holidays. CDRs can also be used to detect behaviour in different groups of people [GSP$^+$19, ZHG22, PF21], improve transportation, security control, and traffic optimization [KGSR14, CBL19, WHM$^+$23], and suggest ways of improving healthcare during national disasters and epidemics [FMWFM11, XHY$^+$20, HLG$^+$21]. These are just a few examples of the many studies in various areas using CDR data.

This study examines mobility and calling patterns during Estonian public holidays in January and February. In particular, we focus on New Year's Day and Independence Day. The two particular holidays were chosen due to the limitations of the dataset period. In this thesis, we study mobility and calling patterns by analyzing anonymized CDR data provided by one of Estonia's leading mobile operators. The data spans a two-month period, from January 2018 to February 2018. The data consists of 56M (million) calls made by 449K (thousand) unique callers.

The study uses descriptive techniques and examines the mobility and calling patterns in Estonia at three levels of granularity: Location (longitude and latitude), Municipality, and County. This approach allows us to examine mobility comprehensively and identify patterns across different municipalities and counties. This study aims to contribute to the existing research on mobility patterns during holidays and provide practical insights for urban planning and management during these time periods. The highlights of this study are as follows:

1. We utilized nationwide and multi-source datasets: (i) CDR data with 56M records spanning 2 months by approximately 449K subscribers distributed over more than 45,000 km^2 and served by over 1K base stations in Estonia. (ii) Geographical information using QGIS for 78 municipalities and 15 counties in Estonia.

2. Correspondingly, the study aims to investigate whether people tend to stay in these locations during Estonian public holidays. Our analysis begins by identifying

individuals' normal mobility patterns. Then, we investigate whether people tend to stay in these locations during Estonian public holidays. This inspired our research question, 'How do mobility and calling patterns differ on public holidays?'

3. The results indicate a correlation between public holidays and mobility patterns on all three location levels. Firstly, people are less likely to stay in their top locations on both holidays, especially in densely populated urban areas. Secondly, people tend to spend their holidays in another municipality, and finally, at the county level, people are more likely to deviate from their usual routines on New Year's Day than on Independence Day.

4. Overall, the results suggest that there are changes in mobility and calling patterns during public holidays, with New Year's Day altering them more when compared to Independence Day and the average mobility.

The rest of the thesis is structured as follows. Chapter 2 gives insight into related works covering previous studies that have used CDR data for mobility research. We then describe the CDR dataset and its key features in Chapter 3. Chapter 4 outlines the methodology used in this study. Chapter 5 presents the results of our descriptive analysis of the CDR dataset, and we conclude with a discussion of limitations and future directions in Chapter 6.

2 Mobility Studies Using CDR data

This chapter covers previous research that employed call record data to study its various applications. This chapter also highlights gaps in the existing literature.

2.1 Urban Mobility

The use of CDR data has become increasingly popular in recent years for studying human mobility and urban dynamics. In [WZL22], the authors examine a large CDR dataset to address human mobility in urban areas from four different perspectives on urban mobility: spatial movements, social phenomena, economic indicators, and policy tools. They discuss current trends and future directions in mobility-driven urban studies, such as combining social and spatial theory, analyzing new forms of mobility, and focusing on equity, ethics, and justice in mobility. However, the work also highlights some challenges, such as the limited representation of the population in mobility datasets and the need to address privacy concerns. Despite these challenges, the authors argue that advancements in mobility concepts, data quality, and analytical methods can lead to better insights and applications of urban mobility knowledge.

In [KAS17], the authors utilize CDR data to investigate changes in residency in Estonia and presented a framework for mapping these changes and an anchor point model. This work emphasizes the need for continuous and long-term time-series data, considering the diversified nature of human mobility and the varying structure of mobile tower networks.

Another study [HPK20], examines large-scale commuting patterns in Estonia using a Hidden Markov Model. The researchers transform the data into meaningful mobility patterns to better understand daily commuting and other urban dynamics. The study also highlights the potential for mobile sensing to help address transportation, urbanization, and sustainability challenges. Furthermore, the approach used in the study can be extended to investigate various socio-economic aspects of mobility, such as economic activities, migration, segregation, community formation, and social interactions.

Additionally, [ASJ+10] explores how to identify meaningful locations for mobile phone users, such as their homes and workplaces. The authors developed an eight-step model for detecting these locations, which was found to be accurate when compared to the Population Register and the number of residents in Estonia's municipalities. This demonstrates the potential for using CDR data to monitor population geography and mobility.

Overall, these studies provide valuable insights into the potential of CDR data for studying human mobility and urban dynamics. While they also highlight some challenges, such as the limited representation of the population in mobility datasets and the need to address privacy concerns, they underscore the need for continued research in this

area. Additionally, they highlight the potential for using CDR data to inform policy and planning decisions in various urban contexts.

2.2 Mobility at Municipality & County Level

Call Data Records can be a valuable tool for studying mobility patterns at the municipality and county levels for various scenarios. For example, CDR data can help distinguish mobility patterns during natural disasters and epidemics and observe seasonal population changes in different counties.

The study [GRK+20] introduced an interactive web-based mapping platform that aims to increase public risk awareness, support data-driven public health and government decision-making, and enhance community responses to the COVID-19 pandemic. This platform uses aggregated smartphone location data at the county level in the United States, providing valuable insights into the behaviour of individuals in each county during the pandemic. Another study, [Tok21] analyzed all 3142 US counties from March 20th to August 20th, 2020, to examine the relationship between mobility and COVID-19 on a broader temporal scale. The authors found that people travelled more out of their counties and made longer and more frequent trips, even as counties implemented stricter policies, increased testing capacity, and more individuals worked from home. The authors discuss movement patterns during the four waves of COVID-19, such as the initial halt in out-of-county travel when the pandemic first hit and the subsequent prevalence of people making more trips after lockdown restrictions were eased. Additionally, the authors' local models also revealed that areas with more COVID-19 cases were associated with less out-of-county travel. Another study [XHY+20] supports this finding by reporting that external travel to other counties decreased by 35% after the US entered the emergency situation but recovered quickly during the partial reopening phase.

Another work [SA10] examines the seasonal variability of the population in Estonian municipalities using over two years of data that observed changes in people's residences and summer houses. The study reveals a stark contrast in the number of inhabitants in municipalities between the summer and winter periods. In addition, the study reports that 84% of municipalities experience an increase in the number of residents during summer, and 16% of municipalities experience a decrease in population during this season. An interesting finding from the study is that the proportion of seasonal relocation in central Estonia is very low. This may be attributed to the fact that central Estonia is situated close to big cities and coastal relocation areas, allowing people with second homes to move easily between locations without being detected as seasonal relocation by the algorithm. The study concludes that approximately 5% of the population changes their residence seasonally. Another study, [JAW14], found that the monthly variability of individual behaviour is up to 17% explained by seasonality.

In summary, these studies demonstrate how mobile phone record data can be used to study mobility between counties and municipalities. The insights gained from these

studies can inform public policy decisions, such as implementing targeted interventions to reduce disease spread during pandemics and managing the seasonal population fluctuations of municipalities.

2.3 Mobility During Public and National Holidays

There are notable differences in mobility during public and national holidays when compared to those on regular weekdays. Several studies have investigated the influence of holidays on traffic fatalities, such as [WCC+21] and [TRXZ20]. The work in [LS06] discovered that weekend days and "all holiday period" days contribute more to traffic variability than weekdays and "non-holiday period" days. These studies indicate that analyzing mobile phone data, particularly CDR data, can assist in improving traffic policies for both regular weekdays and holiday periods.

Another study, [ZLT+18], analyzed travel patterns in Beijing, China, using Poisson point process models. The study confirmed that enterprises and residential areas have a more significant influence on commuting trips on workdays, while the locations of tourist attractions have a significant impact on holiday trips. The authors also found little difference in trip distributions between holidays and workdays in the noon and afternoon periods.

In [DWE15], researchers developed a spatiotemporal detection system for behaviour anomalies using mobile phone data. They identified unusual behaviour patterns associated with a wide range of events, such as religious and official holidays, natural disasters, violence against civilians, and protests. For instance, the study found that there was an unusually high call and movement frequency on New Year's Eve and New Year's Day, likely due to the national holiday of New Year's.

Finally, work in [MSA16] focused on the analysis of ethnic differences in activity locations during public and national holidays in Estonia, specifically the mobility differences between Estonians and the Russian minority. The authors reported that during Estonian public holidays, the number of Estonians increased by 77 per cent and the number of Russian speakers increased by 33 per cent compared to regular days, in terms of overall calls in the country. The study also highlighted that New Year's Day had the most significant increase in the number of Estonians compared to regular days at 170%, followed by Christmas Eve (132%), Victory Day (126%), and Midsummer Day (96%). For Russian speakers, the most substantial changes compared to regular days were Victory Day (111%), Midsummer Day (77%), and New Year's Day (31%). These findings suggest that there are different mobility and calling patterns between Estonians and Russian speakers during holidays.

In conclusion, the studies mentioned above provide compelling evidence that public holidays have a significant impact on mobility patterns and behaviour, and mobile phone data can be a useful tool for analyzing them.

2.4 Tourism

Mobile phone data records can also be a valuable resource for improving the planning and management of inbound tourism. For instance, in 2007, a study analyzed the seasonality of foreign tourists' mobility in Estonia and discovered that it results in significantly different space consumption patterns [AAM+07]. Specifically, coastal areas were found to be more popular for summer tourism, while continental inland areas were preferred for winter tourism.

Similarly, another study in 2008 examined the feasibility of using passive mobile positioning data, such as roaming call activities or movements, to investigate tourism in Estonia [AAR+08]. The researchers found that the correlations with accommodation statistics for the most frequently visited tourist regions were as high as 0.99. However, the correlations were lower in regions with a high number of transit tourists and less tourism infrastructure. The authors also noted a significant increase in calling during the New Year's period and discussed the calling patterns during this time for different nationalities. These findings confirmed the previous study's results [AAM+07] that seasonality shapes tourism patterns, with summer tourism oriented toward western Estonia and the Islands, while winter tourism is focused on cities and inland areas.

Thus, these studies demonstrate the potential of Call Data Records in gaining insights into the seasonality of tourism and developing better planning and management strategies for the industry.

3 Data

This study investigates mobility patterns during public holidays in January and February using Call Data Records (CDRs) provided by an Estonian mobile phone network operator. In particular, our work focuses on mobility during public holidays in January and February. In this thesis, CDR data is used to examine the differences in mobility between public holidays and regular weekdays, focusing on top locations, municipalities, and counties. Additionally, it offers insights into individuals' mobility patterns during the holiday season.

This study utilizes anonymized nationwide CDRs provided by one of Estonia's mobile operators. The data set spans from January 2018 to February 2018 and has 56M call records made by 449K unique callers from ca 11,000 antennas located on ca 1,200 cell sites (or base stations). Figure 1 shows that the dataset locations cover entire Estonia. From location information, we can also observe that there are gaps in the density of the mobile network in rural areas.

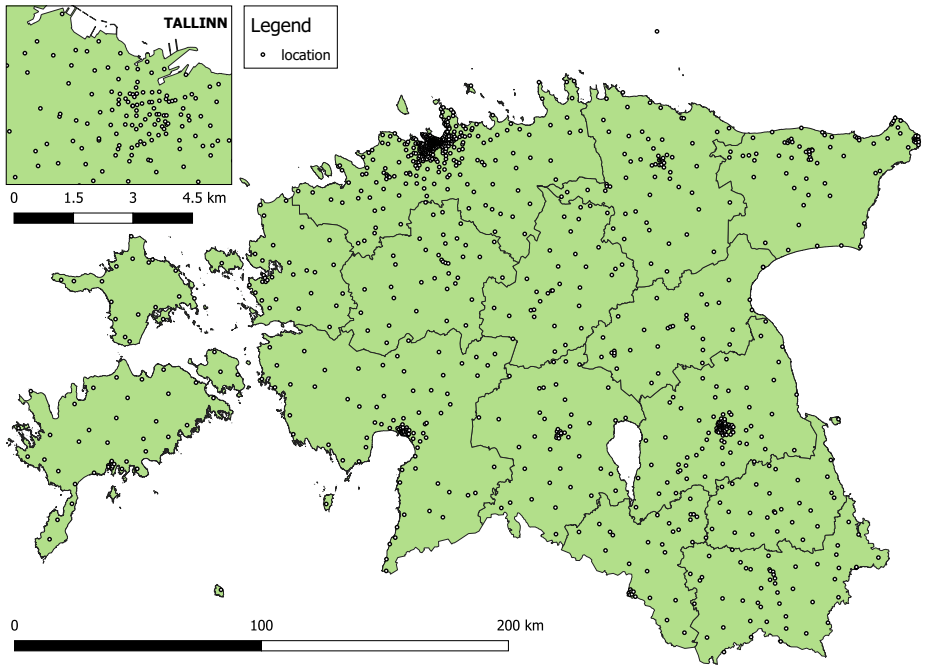

Figure 1. Map with all call locations

A cell site, which contains multiple cells, is a cell phone tower that receives call signals using a number of directional antennas. Each call that is made is picked up by the nearest antenna [Yah19]. Table 1 shows some features of the dataset. We notice that, on average, each caller made 3.3 mobile calls in the data. Additionally, there are more

cell sites than unique locations based on latitude and longitude information, indicating that at some locations multiple cell sites are installed.

Table 1. Key features from the dataset

Feature	Value
Dataset period	01.01.2018 - 28.02.2018
Call amount	ca 56 805 000
Unique callers amount	ca 449 000
Unique locations	ca 1200
Average mobile call activity for caller	3.3

Table 2. Extract from the raw dataset

Caller ID	Receiver ID	Call Time	Cell ID	Site ID	lat	lon
10000000	20000000	2018-02-12 18:00:32	1000	100	59.437321	24.871289
10000001	20000001	2018-01-03 11:31:32	1001	101	59.429531	24.2263767
10000002	20000002	2018-02-26 13:25:15	1002	102	59.326180	24.755

Table 2 shows the data sample, and each call record in the dataset consists of the following information:

- **Caller ID** - the anonymized caller ID
- **Receiver ID** - the anonymized receiver ID
- **Call time** - the call starting date and time in the format of yyyy-MM-dd HH:mm:ss
- **Cell ID** - antenna ID
- **Site ID** - cell site ID
- **lon** - marks the longitude of the caller at the start of the call
- **lat** - marks the latitude of the caller at the start of the call

Note that the call record covers both text messages and mobile calls, as they were not distinguished in the original dataset. That means a row in the dataset can either represent a mobile call or text message originating from ‘Caller ID’ and destined to ‘Receiver ID’.

Data privacy:

This thesis uses anonymized data gathered by an Estonian mobile phone operator. All caller and receiver information had been anonymized by the operator, thus maintaining the privacy of the individuals involved and ensuring GDPR compliance. Moreover, this thesis has rounded up all numbers concerning the exact values derived from the dataset. Additionally, the anonymized data set does not include any personal information about the caller or receiver, nor does it include information about internet usage. The data set was initially gathered for billing purposes rather than for this study.

Preprocessing of the CDR data:

This thesis utilizes CDRs to investigate mobility patterns. In particular, our work focuses on mobility during public holidays in January and February. Therefore, CDR data is used to examine the differences in mobility between public holidays and regular weekdays, focusing on top locations, municipalities, and counties. Additionally, it offers insights into individuals' mobility patterns during the holiday season.

In order to investigate the similarities and differences in mobility patterns for municipalities and counties during public holidays, two new fields were added to the dataset. These additional fields contain information about the originating municipality and county of each call. To calculate this information, the geographic information system QGIS is used. This tool allowed for the placement of call locations (longitude and latitude) on maps that included the respective municipalities and counties. The resulting information is included in the original dataset, and we call this modified dataset as D.

Some sample rows of the dataset D are shown in Table 3. One row of records includes the anonymized caller ID, the call starting date and time, the longitude and latitude of the caller, and the originating municipality and county. Receiver ID is not included in the dataset, as the study only analyzed the caller's mobility.

Table 3. Extract from dataset D with added fields

Caller ID	Call Time	lat	lon	Municipality	County
10000000	2018/02/09 12:09:42	58.114442	27.447500	Räpina	Põlva
10000001	2018/02/20 23:11:01	58.095831	27.463331	Räpina	Põlva
10000002	2018/01/14 17:24:28	57.806106	23.256664	Ruhnu	Saare

4 Methodology

This thesis focuses on studying the unique aspects of mobility during public holidays, particularly the question of whether people tend to stay in a location during these holidays. The concept of a "location" in this study is examined at three granularity levels: top locations, home municipality, and home county. The meaning of these locations is explained in Section 4.1. Furthermore, the study investigates the variations in mobility during New Year's Day and Independence Day, with a particular focus on people from different home municipalities and home counties.

This chapter describes the methodology used to investigate these topics in detail.

4.1 Identify Caller's Top Locations

We begin by identifying each caller's top locations, home municipality, and home county, which are essential to studying individual callers' mobility patterns on a granular level. Here, the term 'top locations' means the two most frequently called-from locations during the dataset time period, identified using the caller's location information. However, it is worth noting that, due to the density of the network towers, the top location represents a broader area than a specific building or address. The 'home municipality' represents the municipality from which the caller made the most calls during the two-month period, and the 'home county' represents the county from which the caller made the most calls.

Using the dataset D, we determine each caller's top locations. For this, we examined all of their call locations and sorted them in descending order of frequency. For each caller, we assigned the most frequently called municipality and county as their home municipality and home county, respectively. Additionally, we identified two locations with the highest frequency as the caller's top locations, as these typically correspond to their home and work [ZB11]. We created separate data named caller 'database' that includes caller ID and four additional fields to identify each caller's top locations, home municipality, and home county. Table 4 shows sample rows of the caller 'database'.

Furthermore, we selected caller IDs that made at least three calls and had at least two meaningful locations in the caller 'database'. This resulted in a total of ca 427,000 distinct callers. These criteria are chosen based on the fact that each caller had an average of 3.3 calls, and for mobility calculations, at least two top locations are needed. The number of unique callers is used in all subsequent calculations.

To gather information about the callers, a new dataset was created with the purpose of being a 'database' of callers and their three-level location data. The dataset included a caller ID field containing all distinct caller IDs, as well as four additional fields to identify each caller's top locations, home municipality, and home county.

To determine each caller's top locations, all of their call locations were examined and sorted in descending order of frequency. The two locations with the highest frequency

were identified as the caller's top locations, as these typically correspond to their home and work [ZB11].

As described in Chapter 3, each call was assigned to an originating municipality and county, thereby allowing for the analysis of mobility patterns between municipalities and counties for individual callers. For each caller, the most frequently called municipality and county were selected as their home municipality and home county, respectively.

Table 4 presents an excerpt from the unique caller 'database'.

Table 4. Excerpt from caller 'database'

Caller ID	Top 1	Top 2	Home Municipality	Home County
10000000	[58.0603, 26.2458]	[57.8377, 27.0220]	Otepää	Valga
10000001	[59.4375, 24.7550]	[59.4397, 24.7511]	Tallinn	Harju
10000002	[59.0030, 22.7484]	[58.9925, 22.7219]	Hiiumaa	Hiiu

By utilizing the home municipality and county information for each caller, it was possible to identify those whose home municipality was located outside of their home county. The analysis revealed that only 0.64% of the callers, or ca 2700 individuals, had their home municipality in a different county than their home county. This proportion is relatively small compared to the total number of distinct callers. Therefore, it can be concluded that the vast majority of callers' calls originate from within their home county.

4.2 Calculation of Tendency

To investigate the research question on the most granular level, this study aimed to determine whether callers tend to remain in their significant locations during public holidays. As discussed in Chapter 4.1, each caller has two designated top locations. By utilizing the modified dataset (as shown in Table 3) that includes all calls with their starting date and time, and the caller 'database' (discussed in Chapter 4.1), it is possible to assess whether callers stayed in their top locations during New Year's Day and Independence Day. The algorithm first identifies whether a caller made a call on the holiday, and if so, it analyzes all calls made by the caller on that day. If the majority of calls were placed from either their top one or top two locations, it is concluded that the caller remained in their top locations during the holiday.

Secondly, the study looked at whether unique callers stayed in their home municipality during public holidays. To determine whether callers stayed in their home municipality during public holidays, a similar algorithm to the one used for identifying top locations was utilized. The algorithm checks whether the caller made any calls during the holiday. If so, all the calls made on that day are gathered and analyzed. If the majority of the calls

came from the caller's home municipality, it is assumed that they stayed in their home municipality during the holiday.

Finally, a similar process was applied to determine whether callers stayed in their home county during public holidays. For example, if the majority of calls originated from the caller's home county, it is assumed that they remained in their home county during the holiday.

To study the research question mentioned in Chapter 4, the algorithms discussed above were applied to callers with certain criteria. These criteria are explained in Chapter 4.1.

4.3 Calculation of Averages

To accurately assess movement patterns during holiday periods, it is important to compare holiday mobility with the average movement patterns during regular weekdays. In this study, the thesis question outlined in Chapter 4 was used to determine the probability of individuals staying in their top locations, home municipality, or home county on average. The period for calculating averages was identical to the dataset period of January–February 2018, but the calculation of average mobility varied for New Year's Day and Independence Day. It is important to note that New Year's Day in 2018 fell on a Monday, so to calculate average mobility for Mondays, all Mondays were included in the calculation except January 1st, 2018, which was New Year's Day. For Independence Day, which occurred on a Saturday, average mobility was calculated for each weekend, excluding the weekend of February 24th, to examine mobility patterns during this holiday period.

The days included in the Monday average were the 8th, 15th, 22nd, and 29th of January and the 5th, 12th, 19th, and 26th of February. The days included in the weekend average were the 6th, 7th, 13th, 14th, 20th, 21st, 27th, and 28th of January, and the 3rd, 4th, 10th, 11th, 17th, and 18th of February. All of the days mentioned above fall into the period of January–February 2018, and the average calculations used the same methodology discussed in Chapter 4.2 for each of the three research questions shown in Chapter 4.

4.4 Used applications

To access the anonymized and aggregated dataset, Remote Desktop Connection was utilized. The dataset, which was originally in a large CSV file format, was processed and analyzed using Jupyter Notebook, Python, and several Python packages. QGIS was used to add municipality and county information for each CDR in the original dataset and create Figure 1. All other figures were created using Datawrapper [LKA23].

5 Results

This chapter presents the results of the research question outlined in Chapter 4 and discusses mobility patterns during the holidays under study compared to average weekday mobility patterns.

The analysis results are presented in Table 5 and 6, which are rounded to the nearest whole number. Chapter 5.1 and 5.2 provide an overview of the calling patterns on New Year's Day and Independence Day. Furthermore, the results are categorized into three subchapters based on the study areas of this thesis and are discussed in greater detail in Chapter 5.3, 5.4, and 5.5. Additionally, Chapter 5.6 presents and discusses the mobility differences at the three previously discussed granularity levels, where the callers are further categorized by their home municipality and home county.

It is important to note that the day of the week on which a holiday falls can influence mobility patterns. In this work, mobility during the dataset period of January to February 2018 was analyzed, with New Year's Day falling on a Monday and Independence Day on a Saturday. Therefore, when comparing holiday movement patterns to the average, this factor should be taken into consideration. The analysis results for averages are shown in the *Average* column of Tables 5 and 6. The calculation process for these averages is discussed in more detail in Chapter 4.3.

Table 5. Mobility on New Year's Day vs Average

	01.01.2018	Average
Top Location	68%	70%
Home Municipality	77%	80%
Home County	90%	81%

Table 6. Mobility on Independence Day vs Average

	24.02.2018	Average
Top Location	66%	66%
Home Municipality	75%	76%
Home County	90%	91%

Table 7. Hourly call amounts during New Year's Day and Independence Day

Hour	01.01	24.02
0	261,000	9200
1	67,000	6100
2	29,000	4600
3	19,000	4000
4	14,000	4000
5	9200	3100
6	7000	4800
7	6600	13,000
8	8500	27,000
9	20,000	46,000
10	43,000	62,000
11	65,000	61,000
12	77,000	64,000
13	77,000	58,000
14	70,000	55,000
15	69,000	52,000
16	63,000	49,000
17	56,000	50,000
18	52,000	44,000
19	45,000	41,000
20	39,000	31,000
21	28,000	25,000
22	16,000	17,000
23	10,000	13,000
Total	1,150,000	742,000

5.1 New Year's Day calling patterns

New Year's Day in Estonia is a day of festivity and is typically celebrated with family and friends. It is a day when many people attend parties, watch fireworks shows, and go to other public events.

On New Year's Day (01.01.2018), a total of ca 1,169,000 calls were made, of which ca 1,150,00 were made by ca 262,000 unique callers meeting the criteria outlined in Chapter 4.1. These calls have been categorized by the hour and are presented in Figure 2 and Table 7, specifically in the column labelled *01.01*.

It is worth noting that most of the calls were made between midnight and 1 am on New Year's Day, which can be attributed to people calling their family and friends to wish them a Happy New Year. The number of calls then gradually decreased from 1 am until 7 am, after which it started to increase again until 12 pm. The sudden increase in calls at 12 pm could be attributed to people waking up and calling those they had not

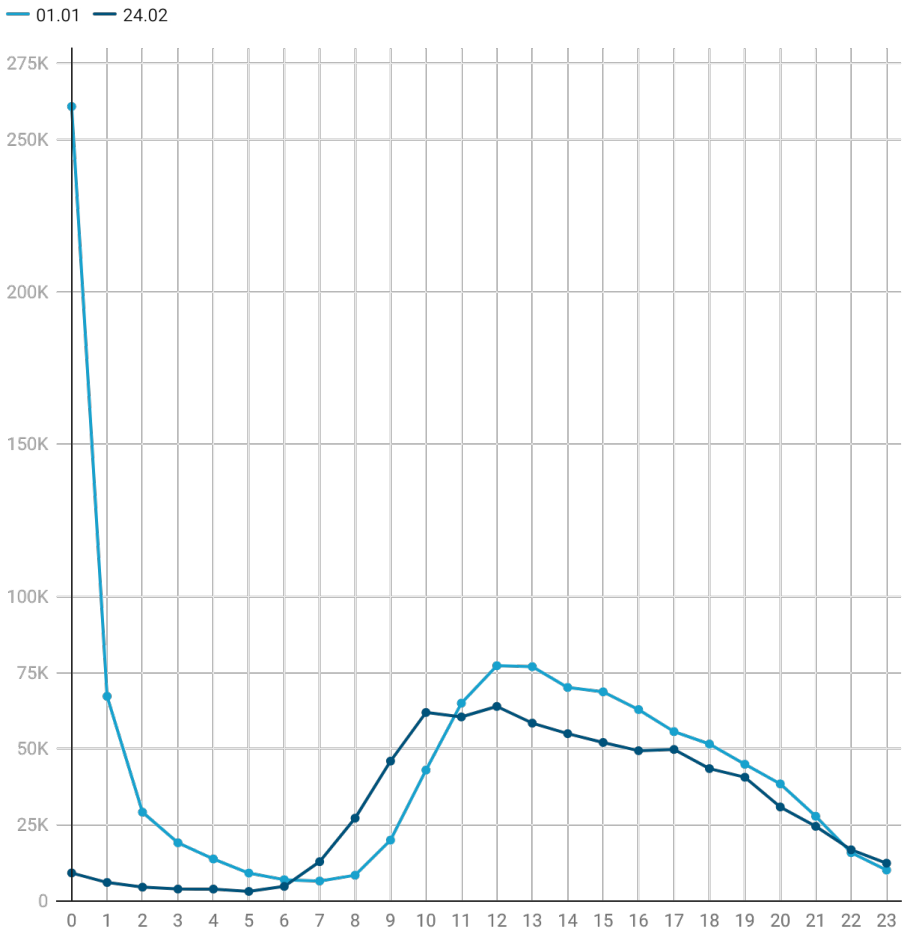

Figure 2. Hourly call graph for New Year's Day and Independence Day

spoken to during the night to wish them a Happy New Year. Alternatively, it could be due to those who did not stay awake past midnight and are now wishing their family and friends a Happy New Year.

5.2 Independence Day calling patterns

Estonian Independence Day, on the 24th of February, is typically a more solemn holiday and is spent watching or attending parades and other celebrations, rather than with grand celebrations with family and friends.

On this day (24.02.2018), a total of ca 756,000 calls were made, with ca 742,000 of those calls made by callers meeting the criteria outlined in Chapter 4.1. These calls have been categorized by the hour and displayed in Figure 2 and Table 7, specifically in the column labelled *24.02*.

Compared to New Year's Day, there were significantly fewer calls made on Independence Day, with roughly a 35% decrease. This is not surprising since Independence Day is not traditionally known as a day for calling family and friends. The highest number of calls on Independence Day was recorded between 12 pm and 1 pm, with ca 63,900 distinct calls, while the least amount of calls were recorded between 5 am and 6 am, with only ca 3,100 calls. It can be inferred that most people were sleeping during that hour, which explains the lower number of calls.

5.3 Do people stay at top locations during public holidays?

This study examines whether people tend to stay in their top locations during public holidays. Table 5 and 6, in the row labelled *Top Location*, show the percentage of people who stayed in their top location on New Year's Day and Independence Day, respectively. The top locations are assumed to be each unique caller's home or work. The column labelled *Average* in both tables displays the average calculation results.

Table 5 shows that, on average, 70% of callers stayed in their top locations. However, on New Year's Day, the percentage of callers who stayed in their top locations decreased to 68%, suggesting that people tend to celebrate holidays in a different location from their home or work. Moreover, since Mondays are typically working days, it is assumed that most citizens stayed in their top locations, which may explain the higher average tendency.

Table 6 shows that, on Independence Day, people were equally likely to stay or celebrate in their top locations as compared to the average, with both results at 66%. This indicates that Independence Day was not a significant reason for people to travel beyond their usual destinations or change their daily or weekly routines. Furthermore, since Independence Day fell on a weekend, it is assumed that people's travel patterns were similar to their typical weekend routines, resulting in no substantial disruptions.

In summary, the data presented in Table 5 and 6 reveal that there was a 2% decrease in the percentage of callers who stayed in their top locations on New Year's Day compared to the average, indicating that people are more likely to change their usual routines and locations to celebrate the holiday. Conversely, on Independence Day, there was no significant difference between the percentage of callers who stayed in their top locations and the average, suggesting that the holiday did not lead to significant disruptions in people's usual routines. These findings highlight the importance of considering the day of the week on which a holiday falls, as it can affect people's mobility patterns and behaviour.

5.4 Do people stay at home municipality during public holidays?

The study also investigated whether callers tend to stay within their home municipality during public holidays. Table 5 and 6 display the percentage of callers who stayed in

their home municipality on New Year's Day and Independence Day, respectively. The row labelled *Home Municipality* presents the results, while the *Average* column of each table shows the overall average.

The data reveals that, on New Year's Day, 77% of callers stayed in their home municipality, while the average percentage of staying in the home municipality was 80%. This suggests that people may prefer to celebrate the holiday elsewhere, such as in another municipality or even outside the county. As a result, there was a 3% difference in the percentage of callers staying in their home municipality on New Year's Day.

Table 6 shows that 75% of callers stayed in their home municipality on Independence Day, with an average of 76%. This implies that the holiday did not significantly impact people's movement from their home municipality. The slight difference of 1% between the holiday and average values suggests that people generally stay close to home on weekends, regardless of the holiday.

In summary, New Year's Day saw a greater deviation from the average in terms of mobility patterns than Independence Day. Despite the differences in how the two holidays are celebrated, the majority of callers remained in their home municipality on both days, with 77% and 75%, respectively. This indicates that people tend to stay close to their usual locations during public holidays. While there is a slight difference in the percentages, it is not statistically significant.

5.5 Do people stay at home county during public holidays?

The third aspect of this work examined whether callers tend to stay in their home county during public holidays. Table 5 and 6 show the percentage of callers who stayed in their home county on New Year's Day and Independence Day, respectively. The *Average* column of both tables displays the overall average.

On New Year's Day, it was observed that 90% of callers stayed in their home county, which is significantly higher than the average of 81% for Mondays during the two-month period. This stark difference of 9% can be attributed to the fact that Mondays are typically working days, and many people work outside their home county, while New Year's Day is a public holiday, meaning a day off. This suggests that people tend to spend New Year's Day in their home county. This suggests that people tend to spend New Year's Day in their home county, possibly because they prefer to celebrate with close friends and family who live nearby and avoid long-distance travel before returning to work on Tuesday.

Table 6 shows that 90% of callers stayed in their home county on Independence Day, which is only slightly lower than the 91% who stayed on average weekends. This indicates that people are not significantly more likely to leave their home county on Independence Day than on other weekends. However, it's worth noting that Independence Day fell on a Saturday, and many people may have taken advantage of the long weekend to travel and celebrate outside of their home county.

Overall, the data shows that people tend to stay in their home county on both New Year's Day and Independence Day. However, the more significant difference lies in the comparison of holiday mobility to average mobility. For instance, there is a notable 9% difference in mobility between New Year's Day and the average Monday. This indicates that people are more likely to stay in their home county on New Year's Day than on a regular workday. On the other hand, the difference in mobility between Independence Day and the average weekend is much smaller, suggesting that people's routines and mobility patterns are relatively consistent on this holiday. This contrast between these two holidays highlights a clear difference in mobility, with New Year's Day being a reason for a change in people's usual mobility.

5.6 Different home municipality and home county mobility comparison

This chapter examines the differences in mobility patterns on New Year's Day and Independence Day and provides a detailed discussion of the variations between municipalities and counties in Chapter 5.6.1 and 5.6.2.

In Estonia, there are 15 counties and 79 municipalities. This study analyzed calls made during a two-month period from all counties and most municipalities, with the exception of Loksa City, where no calls were identified. The number of calls and unique callers varied by region, with the highest number of calls and unique callers coming from Harju County, which includes the capital city of Tallinn, with 26,628,459 calls and 282,035 callers. Tartu County had the second-highest number of calls and unique callers, with 7,461,520 calls and 122,835 callers. It is worth noting that Tartu County is also the second most populous county in Estonia [Ees22], which may explain why it ranked second in terms of calls and callers. These figures were obtained from the original dataset without any caller criteria.

The top five municipalities and counties with the largest number of distinct callers were found to be consistent with the top five municipalities and counties for call volume, as shown in Figure 3 and 4.

Municipality	01.01	24.02
Tallinn City	324,000	238,000
Tartu City	102,000	60,000
Pärnu City	48,000	30,000
Saaremaa Parish	37,000	22,000
Narva City	26,000	22,000

Figure 3. Top 5 municipalities with call amount during holidays

County	01.01	24.02
Harju County	477,000	332,000
Tartu County	163,000	94,000
Ida-Viru County	86,000	64,000
Pärnu County	76,000	48,000
Lääne-Viru County	60,000	35,000

Figure 4. Top 5 counties with call amount during holidays

5.6.1 Calling patterns from different municipalities

Figure 5, 7, 9, 6, 8, and 10 provide an analysis of caller behaviour based on their home municipality, and how likely they are to stay in different locations — top location, home municipality, and home county. The insights provided by these figures are more detailed than the county-level results presented in Chapter 5.6.2. By examining the behaviour of callers at a more granular level, we can better understand their mobility patterns during the holidays.

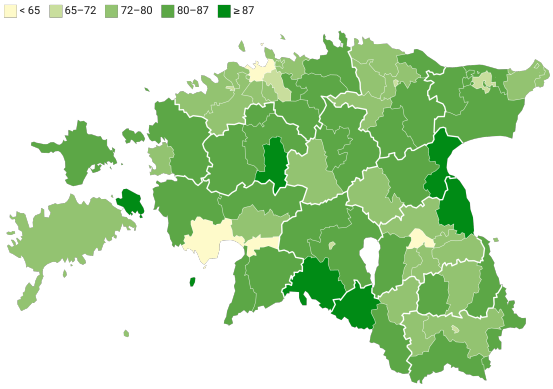

Figure 5. Calling from Top Location on New Year's Day

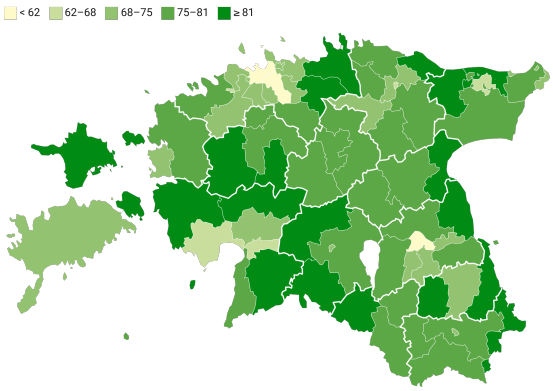

Figure 6. Calling from Top Location on Independence Day

Figure 5, and 6 show the percentage ranges of calls made from top locations on both New Year's Day and Independence Day. On New Year's Day, Kihnu Municipality had the maximum percentage of calls from the top location at 94%, while Tallinn had the minimum percentage at 58%. The average percentage for the holiday was 79%. On Independence Day, Mulgi Municipality had the highest percentage of callers staying in

their home municipalities, with 88%, while Tallinn had the lowest percentage at 55%, and the average was 77%.

The results indicate that people in larger and more urban cities, including the capital city of Tallinn, are less likely to call from their frequent locations on both holidays. While there are minor differences in people's mobility between municipalities on both holidays, the average percentages are relatively low. This suggests that people are unlikely to stay in their home municipalities for most of the holiday.

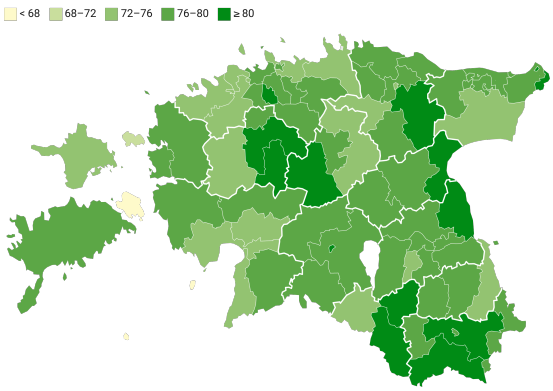

Figure 7. Calling from Home Municipality on New Year's Day

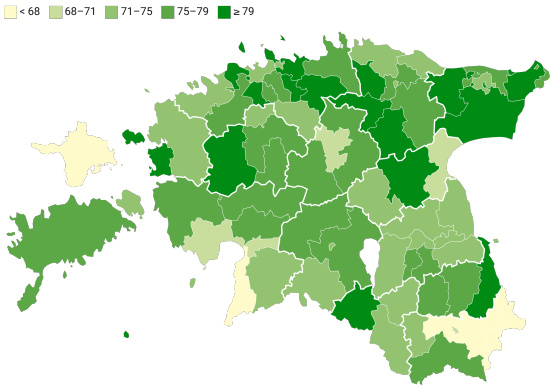

Figure 8. Calling from Home Municipality on Independence Day

Figure 7, and 8 provide insights into the likelihood of callers staying in their home municipalities for New Year's Day and Independence Day. On New Year's Day, the highest percentage of callers staying in their home municipalities was from Valga and Võru Municipality with 83%, while Ruhnu and Kihnu municipalities had the lowest percentage at 64%, and the average was 77%. On Independence Day, the maximum

percentage was from Tõrva and Räpina municipalities, with 82%, and the minimum was from Setomaa Municipality with 64%. The average percentage for the holiday was 76%.

These results suggest that there is no significant difference in people's mobility between municipalities on both holidays. However, it should be noted that the average percentages are relatively low, indicating that people are unlikely to remain in their home municipalities for most of the holiday.

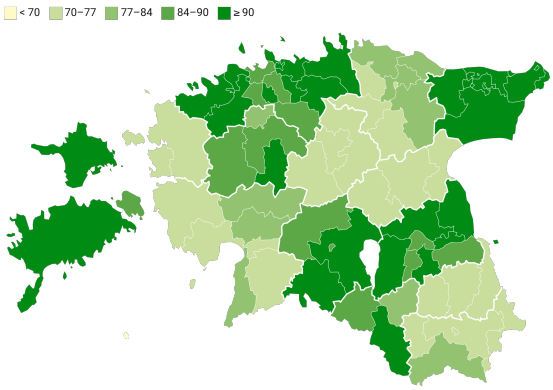

Figure 9. Calling from Home County on New Year's Day

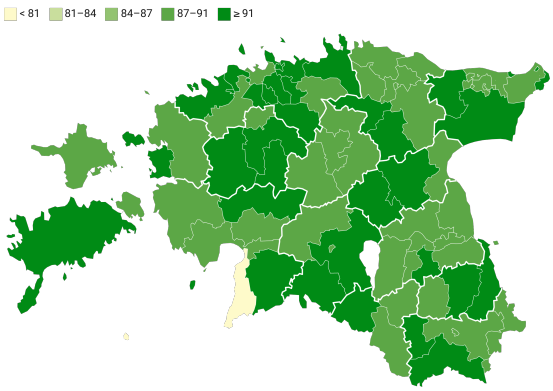

Figure 10. Calling from Home County on Independence Day

Figure 9, and 10 provide insights into the likelihood of callers staying in their home county for New Year's Day and Independence Day. On New Year's Day, the highest percentage of callers staying in their home county was from Narva City at 97%, while Ruhnu Municipality had the lowest percentage at 64%, and the average was 84%. On Independence Day, Kihnu Municipality had the maximum percentage of callers staying in their home county, with 94%, and the minimum was from Häädemeeste Municipality, with 77%. The average percentage for the holiday was 90%.

These results suggest that there are significant differences in people's mobility between counties on both holidays. On Independence Day, the average was much higher, implying that people are more likely to stay close to or in their home county for this holiday.

5.6.2 Calling patterns from different home counties

Figure 11, 12, 13, 14, 15, and 16 display results for calling during holidays for callers categorized by their home county. The figures enable easy identification of changes and consistency for both holidays and across all three levels of location: top location, home municipality, and home county.

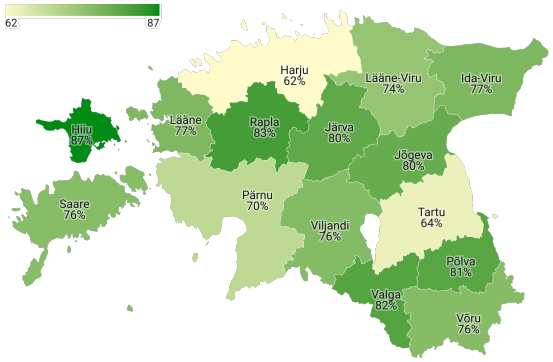

Figure 11. Calling from Top Location on New Year's Day

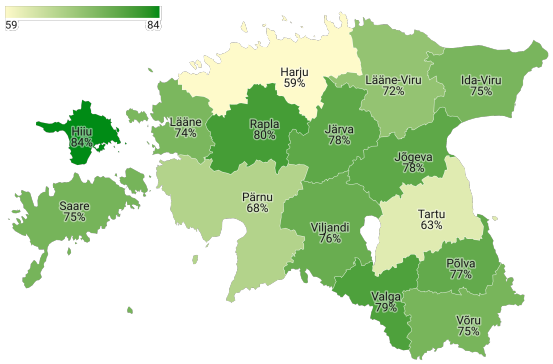

Figure 12. Calling from Top Location on Independence Day

Figure 11 and 12 compare the calling patterns on New Year's Day and Independence Day, divided by county and based on the top locations. The results show notable differences between the two holidays. The legend in the figures indicates a 25% difference

between counties on both holidays, suggesting that people from different counties have different spatial behaviour.

The impact of urbanization is apparent in Harju and Tartu counties, which have the lowest percentages on both holidays. These two counties are the most populous in Estonia and are highly urbanized. The findings, along with the results for Pärnu County, suggest that in urban and densely populated counties, people tend to celebrate holidays in locations other than their primary place of residence or work, possibly with friends and family. Moreover, people in urban areas are likely to move around the county more frequently and stay in different places since there are usually more options in bigger cities. In contrast, in rural counties, there are fewer large city centres, and people tend to visit similar places more frequently.

Despite having a larger population and more calls than Pärnu County on both holidays, people from Ida-Viru County are much more likely to call from their top locations. Ida-Viru County has the highest concentration of Russian-speaking people in Estonia [Sta22], and the study [SAM17] found that the Russian-speaking people have smaller and less diverse activity spaces than Estonians. This can explain the calling patterns seen in Ida-Viru County.

Hiiu County has the highest percentage of people staying in their top location on both holidays, with 87% on New Year's Day and 84% on Independence Day. The small size of Hiiumaa Island likely contributes to this pattern, as people tend to stay in their usual frequent locations. It is also possible that people in Hiiu County are routine-oriented and visit the same places frequently.

To conclude, people are more likely to call from their top location on New Year's Day than on Independence Day. This is evident when comparing the calling patterns from the same county for both holidays, with all counties individually having higher percentages of calls from their top locations on New Year's Day compared to Independence Day.

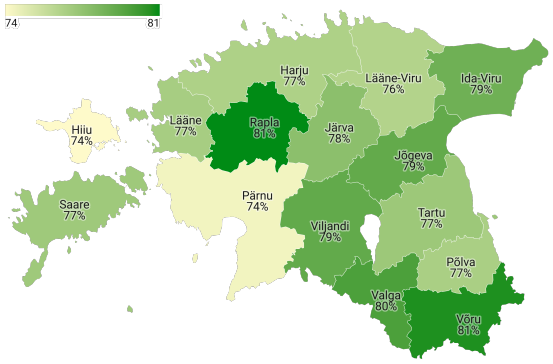

Figure 13. Calling from Home Municipality on New Year's Day

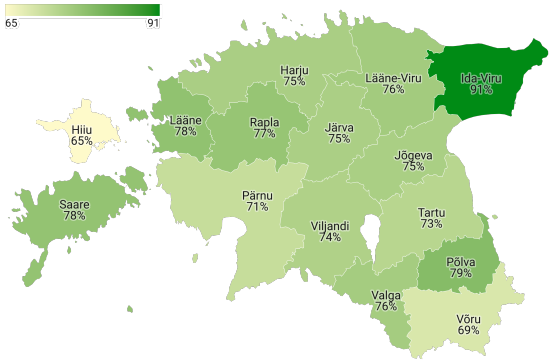

Figure 14. Calling from Home Municipality on Independence Day

As can be seen from Figure 13, and 14 the percentages for staying in one's home municipality are quite low when compared to top location (Figure 11, 12) or home county (Figure 12, 16). These results suggest that people are likely to celebrate the holidays in a location different from their home municipality.

Hiiu County has the lowest percentage of calls from the home municipality on both holidays, with 74% on New Year's Day and 65% on Independence Day. This finding is interesting because it suggests that people from Hiiumaa Island are likely to move around the island a lot or go to the mainland regularly since these results are seen for holidays with very different celebration ways.

It should be noted that Ida-Viru County had the largest percentage of residents remaining in their home municipality on Independence Day. This suggests that the holiday does not change their usual routines, and people are not likely to move around during the holiday. This again confirms the work in [SAM17], that Russian-speaking people have smaller activity spaces than Estonians.

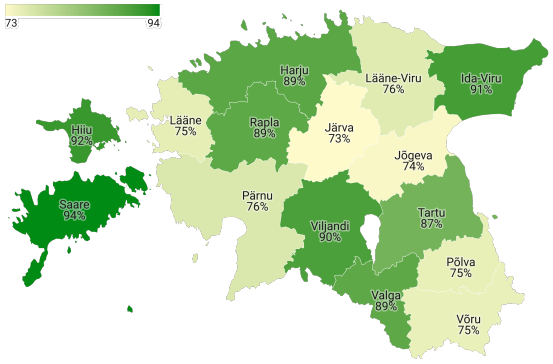

Figure 15. Calling from Home County on New Year's Day

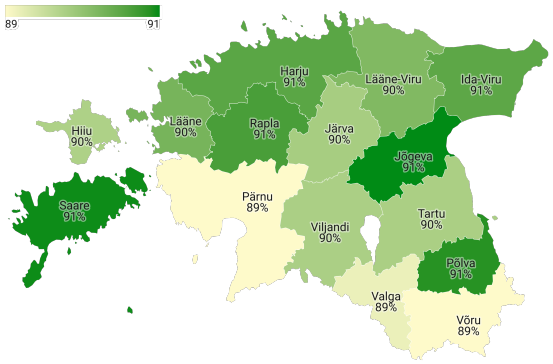

Figure 16. Calling from Home County on Independence Day

Figure 15 and 16 compare the calling patterns from home counties on New Year's Day and on Independence Day, divided by county. The results indicate significant differences between the two holidays, suggesting that Estonians modify their mobility patterns for different holidays.

For several counties, there is an approximate 15% difference in calling patterns between the two holidays, with the percentage being higher on Independence Day. This implies that New Year's Day is a holiday when people are more likely to travel, even further than their home county.

Except for the islands, all other counties have a much higher percentage of people staying in their home county on Independence Day than on New Year's Day. This suggests that people from Estonian islands are more inclined to spend their New Year's celebration close to home and are less likely to travel to the mainland.

In summary, the data indicates that people are slightly more likely to stay in their home county on Independence Day than on New Year's Day. The minimum percentage of people staying in their home county is much lower on New Year's Day, indicating that people are more likely to change their mobility patterns during this holiday.

6 Discussion

The aim of this research was to examine the correlation between public holidays and mobility patterns in Estonia using CDR data. The study analyzed mobility patterns at three different location levels: top locations, home municipality, and home county. The CDR dataset contained around 56M records and 499K distinct callers in January and February 2018.

The findings of this study suggest that public holidays have a significant impact on mobility patterns at all three location levels. Firstly, people are less likely to stay in their top locations during holidays, particularly in densely populated urban areas of Estonia. However, the researchers found that residents of Ida-Viru County were more likely to stay in their top locations during holidays, suggesting that county-level differences may influence people's mobility patterns. Secondly, people are less likely to call from their home municipality on New Year's Day, indicating that people tend to spend their holidays in other municipalities. Furthermore, the study found that residents of Hiiumaa Island were more likely to spend both holidays in another municipality, indicating higher mobility than in other counties. Finally, on the home county level, the study found that people are more likely to deviate from their usual routines on New Year's Day than on Independence Day. This suggests that people tend to change their usual routine on New Year's Day, while Independence Day does not significantly alter their mobility patterns.

Across all three levels, people are more likely to deviate from their usual routines on New Year's Day than on Independence Day. These results imply that people tend to change their usual routine on New Year's Day, while Independence Day does not significantly alter their mobility patterns.

In conclusion, this study provides novel insights into the connection between holidays and spatiotemporal movement, with potential benefits for urban planning and resource allocation during holidays.

6.1 Limitations

This study has several limitations that should be acknowledged. The amount of available data restricted the examination of mobility patterns to two public holidays in Estonia. While these findings provide a valuable starting point, further research is needed to fully understand mobility patterns during other public holidays and seasons.

The study was also constrained by the limited coverage of the Estonian mobile network in rural areas, particularly in analyzing mobility for top locations. As a result, there is a notable discrepancy in network density between urban and rural regions, which may have affected the accuracy of the results in less populated areas. A more comprehensive mobile network would enable a more precise understanding of mobility patterns throughout Estonia and help to address this issue.

6.2 Future Work

To further enhance the insights gained from this study, future research should aim to collect a larger dataset that covers a significant portion of the population. Specifically, a dataset that captures mobility patterns during multiple public holidays across different seasons can provide a more comprehensive understanding of holiday-related mobility. This can aid policymakers in identifying patterns of demand and supply for transportation and resources and helping them allocate them efficiently.

Furthermore, a longer study period can reveal long-term mobility patterns and changes in behaviour over time. For instance, studying mobility patterns over the years can provide insights into how demographic factors such as age, income, and family size affect holiday mobility.

Finally, conducting cross-country studies on holiday-related mobility patterns can offer broader insights and provide a comparative analysis of global holiday mobility patterns. This can aid policymakers in designing effective holiday management strategies that take into account the differences in holiday-related mobility patterns across different regions and countries.

References

[AAM+07] Rein Ahas, Anto Aasa, Ülar Mark, Taavi Pae, and Ain Kull. Seasonal tourism spaces in estonia: Case study with mobile positioning data. *Tourism Management*, 28(3):898–910, 2007.

[AAR+08] Rein Ahas, Anto Aasa, Antti Roose, Ülar Mark, and Siiri Silm. Evaluating passive mobile positioning data for tourism surveys: An estonian case study. *Tourism Management*, 29(3):469–486, 2008.

[ASJ+10] Rein Ahas, Siiri Silm, Olle Järv, Erki Saluveer, and Margus Tiru. Using mobile positioning data to model locations meaningful to users of mobile phones. *Journal of Urban Technology*, 17(1):3–27, 2010.

[CBL19] Clayson Celes, Azzedine Boukerche, and Antonio A. Loureiro. Crowd management: A new challenge for urban big data analytics. *IEEE Communications Magazine*, 57(4):20–25, Apr 2019.

[DWE15] Adrian Dobra, Nathalie E. Williams, and Nathan Eagle. Spatiotemporal detection of unusual human population behavior using mobile phone data. *PLOS ONE*, 10(3), 2015.

[Ees22] Statistikaamet Eesti. Rv069u: Rahvastik sünniriigi/kodakondsuse, maakonna, soo ja vanuserühma jÄrgi, 1.jaanuar. haldusjaotus seisuga 01.01.2018, May 2022.

[FMWFM11] Enrique Frias-Martinez, Graham Williamson, and Vanessa Frias-Martinez. An agent-based model of epidemic spread using human mobility and social network information. *2011 IEEE Third International Conference on Privacy, Security, Risk and Trust and 2011 IEEE Third International Conference on Social Computing*, 2011.

[GRK+20] Song Gao, Jinmeng Rao, Yuhao Kang, Yunlei Liang, and Jake Kruse. Mapping county-level mobility pattern changes in the united states in response to covid-19. *SSRN Electronic Journal*, Jun 2020.

[GSP+19] Sihui Guo, Ci Song, Tao Pei, Yaxi Liu, Ting Ma, Yunyan Du, Jie Chen, Zide Fan, Xianli Tang, Yong Peng, and et al. Accessibility to urban parks for elderly residents: Perspectives from mobile phone data. *Landscape and Urban Planning*, 191:103642, 2019.

[HLG+21] Xiao Huang, Junyu Lu, Song Gao, Sicheng Wang, Zhewei Liu, and Hanxue Wei. Staying at home is a privilege: Evidence from fine-grained mobile phone location data in the united states during the covid-

19 pandemic. *Annals of the American Association of Geographers*, 112(1):286–305, 2021.

[HPK20] Amnir Hadachi, Mozhgan Pourmoradnasseri, and Kaveh Khoshkhah. Unveiling large-scale commuting patterns based on mobile phone cellular network data. *Journal of Transport Geography*, 89:102871, Dec 2020.

[JAW14] Olle Järv, Rein Ahas, and Frank Witlox. Understanding monthly variability in human activity spaces: A twelve-month study using mobile phone call detail records. *Transportation Research Part C: Emerging Technologies*, 38:122–135, 2014.

[KAS17] Pilleriine Kamenjuk, Anto Aasa, and Jaanus Sellin. Mapping changes of residence with passive mobile positioning data: The case of estonia. *International Journal of Geographical Information Science*, 31(7):1425–1447, 2017.

[KGSR14] Kevin S. Kung, Kael Greco, Stanislav Sobolevsky, and Carlo Ratti. Exploring universal patterns in human home-work commuting from mobile phone data. *PLoS ONE*, 9(6), 2014.

[LKA23] Mirko Lorenz, David Kokkelink, and Gregor Aisch. Create charts, maps, and tables, Mar 2023.

[LS06] Zhaobin Liu and Satish Sharma. Statistical investigations of statutory holiday effects on traffic volumes. *Transportation Research Record: Journal of the Transportation Research Board*, 1945(1):40–48, Jan 2006.

[LSS+22] Shengjie Lai, Alessandro Sorichetta, Jessica Steele, Corrine W. Ruktanonchai, Alexander D. Cunningham, Grant Rogers, Patrycja Koper, Dorothea Woods, Maksym Bondarenko, Nick W. Ruktanonchai, and et al. Global holiday datasets for understanding seasonal human mobility and population dynamics. *Scientific Data*, 9(1), 2022.

[MSA16] Veronika Mooses, Siiri Silm, and Rein Ahas. Ethnic segregation during public and national holidays: A study using mobile phone data. *Geografiska Annaler. Series B, Human Geography*, 98(3):205–219, 2016.

[PF21] Gergő Pintér and Imre Felde. Analyzing the behavior and financial status of soccer fans from a mobile phone network perspective: Euro 2016, a case study. *Information*, 12(11):468, 2021.

[SA10] Siiri Silm and Rein Ahas. The seasonal variability of population in estonian municipalities. *Environment and Planning A: Economy and Space*, 42(10):2527–2546, 2010.

[SAM17] Siiri Silm, Rein Ahas, and Veronika Mooses. Are younger age groups less segregated? measuring ethnic segregation in activity spaces using mobile phone data. *Journal of Ethnic and Migration Studies*, 44(11):1797–1817, 2017.

[Sta22] Eesti Statistikaamet. Rv0222u: Rahvastik soo, rahvuse ja maakonna jÄrgi, 1. jaanuar. haldusjaotus seisuga 01.01.2018, Jun 2022.

[Tok21] Ahmad Ilderim Tokey. Spatial association of mobility and covid-19 infection rate in the usa: A county-level study using mobile phone location data. *Journal of Transport amp; Health*, 22:101135, 2021.

[TRXZ20] Yuni Tang, Kendra L. Ratnapradipa, Henry Xiang, and Motao Zhu. Motor vehicle fatalities during memorial day weekends, 1981–2016. *BMC Research Notes*, 13(1), 2020.

[WCC+21] Bayu Satria Wiratama, Ping-Ling Chen, Liang-Hao Chen, Wafaa Saleh, Shang-Ku Chen, Hui-Tsai Chen, Hui-An Lin, and Chih-Wei Pai. Evaluating the effects of holidays on road crash injuries in the united kingdom. *International Journal of Environmental Research and Public Health*, 18(1):280, 2021.

[WHM+23] Zi Wang, Jia Hu, Geyong Min, Zhiwei Zhao, Zheng Chang, and Zhe Wang. Spatial-temporal cellular traffic prediction for 5g and beyond: A graph neural networks-based approach. *IEEE Transactions on Industrial Informatics*, 19(4):5722–5731, 2023.

[WZL22] Ruoxi Wang, Xinyuan Zhang, and Nan Li. Zooming into mobility to understand cities: A review of mobility-driven urban studies. *Cities*, 130:103939, 2022.

[XHY+20] Chenfeng Xiong, Songhua Hu, Mofeng Yang, Weiyu Luo, and Lei Zhang. Mobile device data reveal the dynamics in a positive relationship between human mobility and covid-19 infections. *Proceedings of the National Academy of Sciences*, 117(44):27087–27089, 2020.

[Yah19] Salah I. Yahya. The use of camouflaged cell phone towers for a quality urban environment. *UKH Journal of Science and Engineering*, 3(1):29–34, 2019.

[ZB11] Hui Zang and Jean Bolot. Anonymization of location data does not work. *Proceedings of the 17th annual international conference on Mobile computing and networking*, 2011.

[ZHG22] Li Zhong, Vincent Huang, and Steve Guo. Mobile phone paradox: A two-path model connecting mobile phone use and feeling of loneliness for filipino domestic workers in hong kong. *Mobile Media amp; Communication*, 10(3):448–467, 2022.

[ZLT+18] Shen Zhang, Xin Liu, Jinjun Tang, Shaowu Cheng, and Yinhai Wang. Urban spatial structure and travel patterns: Analysis of workday and holiday travel using inhomogeneous poisson point process models. *Computers, Environment and Urban Systems*, 73:68–84, Nov 2018.

Appendix

I. Licence

Non-exclusive licence to reproduce thesis and make thesis public

I, **Laura Liisa Koldekivi**,
*(*author's name)

1. herewith grant the University of Tartu a free permit (non-exclusive licence) to

   reproduce, for the purpose of preservation, including for adding to the DSpace digital archives until the expiry of the term of copyright,

   Mobility Pattern Analysis using CDR: A Case Study of Estonian Public Holidays in January & February,
   *(*title of thesis)

   supervised by Rahul Goel, Anto Aasa and Rajesh Sharma.
   *(*supervisor's name)

2. I grant the University of Tartu a permit to make the work specified in p. 1 available to the public via the web environment of the University of Tartu, including via the DSpace digital archives, under the Creative Commons licence CC BY NC ND 3.0, which allows, by giving appropriate credit to the author, to reproduce, distribute the work and communicate it to the public, and prohibits the creation of derivative works and any commercial use of the work until the expiry of the term of copyright.

3. I am aware of the fact that the author retains the rights specified in p. 1 and 2.

4. I certify that granting the non-exclusive licence does not infringe other persons' intellectual property rights or rights arising from the personal data protection legislation.

Laura Liisa Koldekivi
09/05/2023