WHO SKIS WHERE, WHEN? – QUANTIFYING THE BACKCOUNTRY POPULA-TION IN TROMSØ, NORWAY

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ABSTRACT: It is generally accepted that backcountry skiing is becoming increasingly popular, even though there are no effective ways to count exactly how many backcountry skiers are out there. Without this information, making well-reasoned decisions based on avalanche fatality statistics is challenging. In this study, we have tested three different methodologies from 2019-2024 to enumerate the backcountry population in the Tromsø region, Norway (2600 km^2). First, we attempted to use signaling data from telecom networks. This method leverages the fact that most modern phones continuously share data with the telecom network, creating signaling data that contains information about which coverage area the phone is connected to. Despite the common belief, there is no accurate triangulation, making it impossible to know whether a phone is moving or stationary within the coverage area. However, tracking the phone's movement through different coverage areas is possible. We utilized this method by tracking the number of phones traveling from residential areas to avalanche-prone terrain for the 2019-2020 winter season. Secondly, we developed a large network of beacon checkers—small, waterproof devices that detect and count signals from avalanche transceivers. The beacon checkers were placed out at the most used trailheads around Tromsø (from 2021-2024) together with a large sign, battery, solar panel, and a data logger that transmits the number of counts every three hours to a database using IoT/LTE technology. The counts were validated using a time-lapse camera, taking images every 30 seconds during a two-month period. Finally, we made a cheap, small, battery-powered device that constantly searches for Bluetooth Low Energy (BLE) signals, as most backcountry skiers are likely to wear at least one BLE unit (e.g. phone, watch, wireless headset etc.) A proof-of-concept device was tested with promising results during the 2022-2023 season, fol-lowed by a full-scale test of 30 units during the 2023-2024 season. Our study not only demonstrates the use of different methodologies but also advances the understanding of the backcountry skiing population in Tromsø. By quantifying a large proportion of the overall population, we provide accurate and valuable data that can inform future decisions and policies.

Keywords: counting people; signaling data; beacon checkers; bluetooth low energy; monitoring system

1. INTRODUCTION

Backcountry skiing has a considerable social and economic impact in Northern Norway. Tourism is Norway's fifth largest export industry and is experiencing significant growth, particularly in individualistic and often risk prone activities (NOU (2023)). Official records show that in the past 10 years (2014-2024), 750 people have been caught in avalanches in Norway. The actual number is likely higher due to underreporting. Out of the 750 incidents, there were 58 fatalities and 62% of these occurred in Northern Norway (Toft et al. (2023b)).

Most municipalities in Northern Norway are small and have limited resources, relying heavily on the economic opportunities' backcountry skiing provides. Consequently, any change in avalanche risk could directly or indirectly impact a significant proportion of the population. Moreover, numerous avalanche incidents with frequent search and rescue operations are unsustainable for these small communities (Toft (2024)).

Over the last two decades, the number of yearly avalanche related fatalities (10-year average) has increased from 3 to 6.5 in Norway (Toft et al. 2023). During the same period, the proportion of people doing backcountry skiing in Switzerland has increased from 1.5% in 2008 to 3.4% in 2020 (Lamprecht et al. (2014); Bürgi et al. (2021)). These numbers are from a large cross-sectional which are repeatedly conducted in Switzerland. No such data is available in other countries as we are aware of to date. Furthermore, there is no reliable method of directly or indirectly counting the number of backcountry skiers at different times and locations at regional to national scales (Toft et al. (2023a)).

From 2019 to 2024, we have attempted three different methods to enumerate backcountry skiers within the Tromsø forecasting region throughout the win-

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ter season. This is important, because without an accurate understanding of the number of skiers in an area (background information), it is impossible to estimate an accurate fatality rate. The absence of background information combined with only using fatality and incident data provides an incomplete understanding of risk at the population level, and any changes in the fatality rate over time (Toft et al. (2023a)).

1.1 Study area

The study area is the surrounding area round the Tromsø municipality (Figure 1).

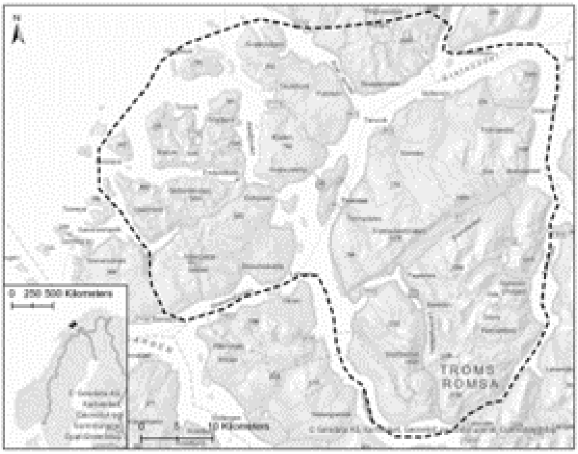

Figure 1: The study area is marked with a dashed line. Tromsø is the archipelago in the center of the map.

2. METHODS

First, we attempted to use signaling data from telecom networks from 2019-2020 (Toft et al. (2023b)). Secondly, we developed a network of 25-30 beacon checkers which were active from 2021 to 2023. It is a small, waterproof device that detect and count signals from avalanche transceivers (Toft et al. (2023a)). Third, we made a cheap, small, battery-powered device that constantly searches for Bluetooth Low Energy (BLE) signals. A proof-of-concept device was tested with promising results during the 2022-2023 season, followed by a full-scale test of 30 units during the 2023-2024 season.

2.1 Signaling data[*]

Telia, one of the largest mobile network providers in Norway utilizes telecom network data, one of the most extensive and constantly generated data sources, to provide insights into national movement patterns without compromising individual privacy. This methodology, compliant with General Data Protection Regulation (GDPR), ensures anonymity by aggregating data into groups and not storing or processing identifiable information. The process involves the use of signaling data, generated by smartphones during active or passive use, which includes a timestamp, and the coverage area (Cell ID) connected to the phone.

The best server estimate (BSE), which is the estimated coverage area, is defined for each Cell ID and offers a more precise location compared to solely using the Base Transceiver Station (BTS) by linking multiple Cell IDs associated with different antennas. Although Telia does not employ triangulation due to privacy policies, analyzing signaling data over time allows for the creation of movement chains, which are particularly useful in urban areas but have in this study also been applied to assess movements in avalanche terrain. Telia's methodology involves three types of reports: Activity reports that show where crowds spend time, Routing reports that track passing crowds, and Origin-Destination reports that detail trips between locations. For this study, we focus on the Activity report, which quantifies the time spent by subscribers in a specific area, adjustable in resolution to maintain privacy compliance.

This approach has been applied to a case study in Tromsø, Northern Norway, where avalanche terrain and populated areas were defined using GIS software. Populated areas were determined based on the number of inhabitants per square kilometer, while avalanche terrain was classified according to the ATES framework (Larsen et al. (2020)). To avoid noise from other activities, any avalanche terrain within 300 m of a house or road was excluded.

A mobility analysis was conducted by sharing the defined layers with Telia, who then distinguished between populated and avalanche-prone areas using their BSE. This enabled the counting of phones moving into avalanche terrain, with additional filters applied to consider only those in the terrain for a sufficient duration during daylight hours, accounting for typical backcountry trip durations and times. The study also explores correlations between the number of people in avalanche terrain and various factors such as daylight, avalanche forecast page views, weekends and holidays, weather conditions, and avalanche danger levels. These correlations help understand the influence of different factors on backcountry usage and can inform safety measures and resource allocation for avalanche prevention and response.

The validation process involves an algorithm developed by Telia to assign the most likely position within

[*] Sections with this mark includes text that is re-used from Håvard B. Toft's Ph.D. thesis (Toft (2024)).

a Cell ID. The algorithm is trained on data from populated areas and roads. We combine the output from this algorithm with GPS data from two known phones.

2.2 Beacon checkers*

To quantify backcountry skiers, a checkpoint (CP) sign equipped with a low-power consumption beacon checker (BC) system were deployed at trailheads throughout the study area. The BCs, operating on a 12V system, wakes up every 15 seconds to detect nearby avalanche transceivers. To ensure continuous operation throughout the winter season, the system was supported by solar panels and robust LiFePo4 batteries, allowing the BCs to function effectively even during Tromsø's prolonged polar nights. Data was transmitted to a database every three hours using the mobile network (Figure 2).

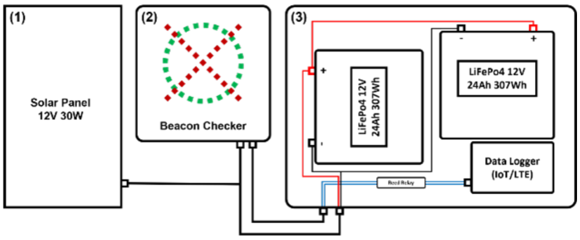

Figure 2: The technical system consists of three parts: (1) a solar panel, (2) a BC and (3) a hard case with 2 batteries and a data logger (from Toft et al. (2023a)).

The BCs were designed to count all avalanche beacon signals within a certain range, without distinguishing between individual skiers, potentially leading to overcounts if individuals passed multiple times. To select optimal locations for these CPs, the study utilized the Strava Heatmap and consulted with local avalanche experts, resulting in 29 strategically placed CPs for the initial season. The system's reliability was maintained through regular maintenance and the use of silica gel to prevent moisture accumulation inside the devices. To validate the BC counts and address the issue of non-unique counts, a time-lapse camera was set up at a distance to observe three high-traffic trailheads covering six CPs. This method allowed for the comparison of actual skier numbers with BC data while adhering to privacy laws by ensuring individuals couldn't be identified in the images. This validation step was crucial for assessing the accuracy of the BC data and making necessary adjustments to account for the system's inherent limitations in distinguishing unique individuals.

2.3 Bluetooth Low Energy

Another solution to enumerate backcountry skiers at different trailheads are BLE counters (also known as BLE sniffers). We have developed our own device using an Arduino Nano BLE 33 combined with a IoT/LTE pulse counter. The device is powered by a 3.7V 14,000 mAh battery, and by enabling power save measures on the Arduino, we have been able to get the average power consumption down to 1 mA, resulting in a theoretical battery life of 580 days. The device is waterproof (IP67) with the dimensions 6x12x18 cm. The weight is approx. 750 grams and the material cost for one unit is approx. USD 250 (Figure 3).

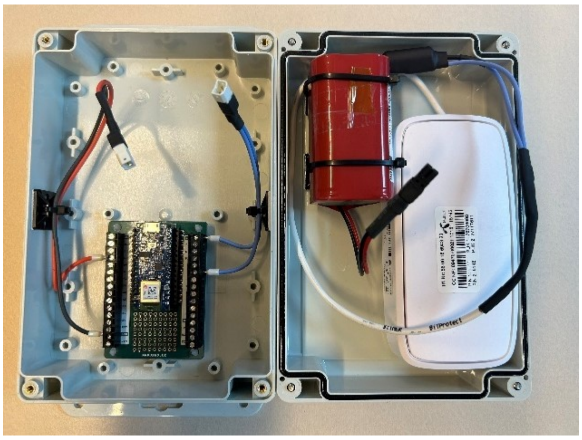

Figure 3: The internals of a BLE counting device. The Arduino Nano BLE 33 is the circuit board (left), the battery (red) and pulse counter (white).

A proof-of-concept device was tested with promising results during the 2022-2023 season, followed by a full-scale test of 30 units during the 2023-2024 season. The counts would need to be validated using similar methods as used to validate the BC counts (i.e. time lapse camera). The study is ongoing.

3. RESULTS

3.1 Signaling data*

The mobility analysis revealed that an estimated 13,666 individuals spent at least two hours in avalanche terrain during the 2019-2020 sea-son, with daily figures ranging from none to 118 people, averaging 75 individuals per day. The analysis showed a weak but statistically significant correlation between the number of people in avalanche terrain and factors such as daylight, weekends, holidays, and avalanche forecast page views, with daylight having the most substantial correlation. Other weather-related factors like precipitation, wind, daily avalanche danger, and cloud cover did not show a significant correlation.

The positional validation, conducted using a specially configured phone that allowed comparison between telecom signaling data and precise GPS locations, highlighted notable discrepancies. The estimated positions from signaling data often placed individuals in less accurate locations, such as valley bottoms or along roads and fjords, rather than their actual GPS-tracked positions (Figure 4).

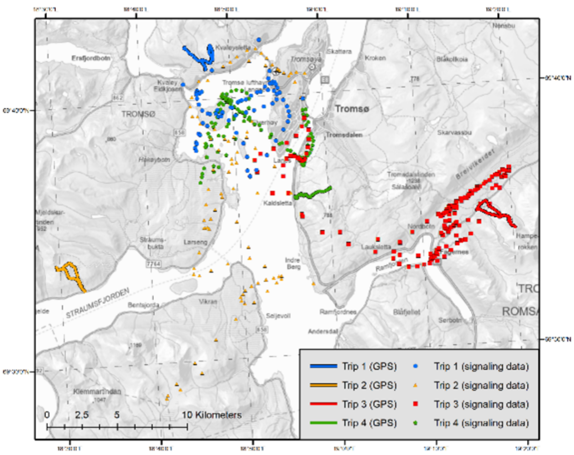

Figure 4: Example using four validation trips (line) compared to estimated positions using signaling data (dots), from Toft et al. (2023b).

The discrepancy between the signaling data and GPS locations varied widely, with a median difference of 6,523 meters and 95% of the points within 12,920 meters, indicating that while useful for broad movement patterns, signaling data cannot be used to pinpoint whether a skier is in avalanche terrain or not.

*3.2 Beacon checkers**

During the first season from 2021-2022, our aim was to deploy 29 CPs around Tromsø, to monitor backcountry skier traffic. Unfortunately, three of these CPs faced operational issues, leaving 26 CPs with an average downtime of 3.54%. In the subsequent season of 2022-2023, the plan was to set up 25 CPs. However, two failed to collect data, but the remaining 23 CPs showed a significant improvement in reliability, with a mere 0.19% downtime.

Validation of the BC counts was conducted using a time-lapse camera, which faced its own challenges, including erroneous setup and environmental conditions that rendered a third of the images unusable. Of the 101,470 usable images from 75 days, manual analysis identified 1,399 individuals passing the CPs, allowing a calibration of the count data to reflect the number of unique trips. We identified that for trailheads where the path leading away from the parking lot is confined, it's nearly impossible to avoid being counted in both directions. We have illustrated this problem in Figure 1, using two types of scenarios. In type 1, the CPs are positioned in such a way that skiers are likely to pass by them only once, typically at the beginning of their trip. Type 2 CPs on the other hand, are located where geographical or trail layout constraints cause skiers to pass by the CP both at the start and end of their trip, leading to potential double-counting of individuals (Figure 5).

Figure 5: In most locations, the CP is placed so that it is logical to pass it on the ascent, while there is much room to avoid it on the descent (scenario 1). However, in some locations, it is most convenient to pass it on both the ascent and the descent (scenario 2). The figure is from Toft et al. (2023a).

After calibrating our count data to the number of unique, the data confirmed that for every person counted at a Type 1 CP, there was nearly a one-to-one correspondence (87%), whereas Type 2 CPs showed almost double the counts per person (192%), suggesting some overcounting due to the system's inability to distinguish unique individuals. The analysis of skier traffic revealed distinct patterns by time of day, week, and month. Skier activity increased from the early morning, peaking between 08:00 and 09:00, and gradually decreased until the evening, with some nighttime activity observed (Figure 6).

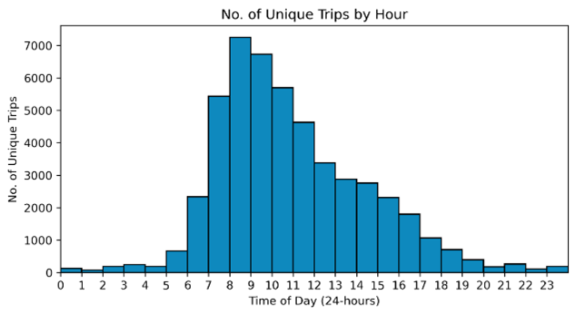

Figure 6: No. of trips as a function of time of day (from Toft et al. (2023a)).

Weekends saw the highest traffic, with a steady increase in activity from Monday to Friday (Figure 7).

Monthly data showed a growing trend from December to April, with March and April being the most popular months, followed by a decrease in May (Figure 8).

Seasonal comparison highlighted consistent skier traffic across both seasons, with a notable mid-

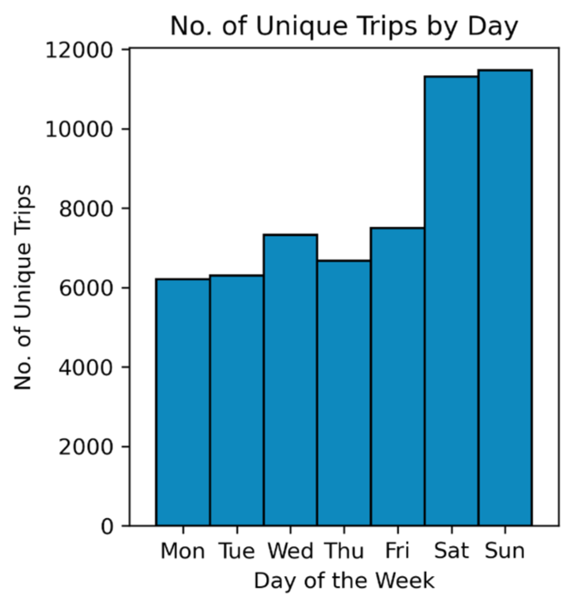

Figure 7: No. of trips as a function of day of week (from Toft et al. (2023a)).

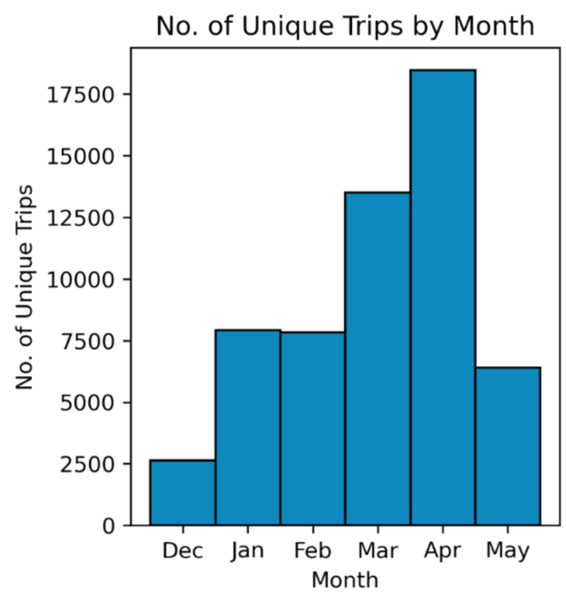

Figure 8: No. of trips as a function of month of year (from Toft et al. (2023a)).

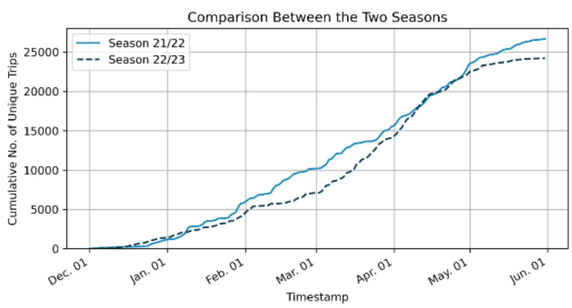

Figure 9: Seasonal comparison of the 2021-2022 season vs. the 2022-2023 season (from Toft et al. (2023a)).

season peak in February during the first season. The second season saw a more spread out increase in activity, culminating in a high at the season's end (Figure 9).

These findings underline the effectiveness of CPs in monitoring skier traffic and the importance of operational reliability for accurate data collection.

3.3 Bluetooth Low Energy

The study using BLE counters to enumerate backcountry skiers in Tromsø is still ongoing and we do not have any specific results to showcase for this ISSW proceeding.

4. DISCUSSION

*4.1 Signaling data**

First, we attempted to use signaling data from Telia, one of the largest mobile network providers in Norway. The main advantage of this method was that if successful, it could be scaled to cover all of Norway. The initial results were very promising. However, when we validated our results, we found that there were substantial discrepancies between the estimated positions from Telia and the GPS reference positions. In essence, this meant that our results were not trustworthy, and we abandoned this method to get an estimate of the total amount of backcountry skiers within a region. The method also had its limitation as it is a relatively crude measure, meaning that we do not get any details on skier's terrain choices.

This study serves as an important lesson learned in understanding the limitations and potential of using telecom data for movement analysis in remote outdoor settings. The study identifies some important limitations regarding the use of telecom data for tracking movements in avalanche prone areas. The large difference between estimated positions and GPS reference data shows the limitations of using signaling data for precise location tracking in non-urban areas. An important factor for this inaccuracy appears to be the lower density of base transceiver stations (BTS) in non-urban areas where most avalanche terrain is located. To make telecom data a viable option to enumerate skiers in avalanche terrain, the density of BTS should be much higher than what is currently available. In areas with a higher density BTS the results may be different.

*4.2 Beacon checkers**

As signaling data is a crude measure of backcountry skiers, we also worked on a method using a large network of beacon checkers at common trailheads around Tromsø. Most mountains that are being used for backcountry skiing in Tromsø have an established starting point. Our hypothesis was that if we identified these sites and placed a large sign with a beacon checker between the parking lot and the most common route, most skiers would walk by to check whether their beacon is working properly. By including a data logger on these signs, we could monitor how many skiing trips that is being done at different trailheads each day or time of day. However, as beacon checkers is not an established method to count backcountry skiers, we first had to validate whether we could use these beacon checkers to get an accurate count of skier trips in the area.

To validate our results, we used a time-lapse camera to compare the actual number of skier trips with the counts from each beacon checker. This enabled us to calculate a ratio which could be used to calculate the actual number of skier trips instead of number of beacon checker counts. We believe that our results represent a substantial methodological progress in terms of measuring backcountry usage at a regional scale. We have successfully measured a large part of the backcountry usage over an area of 2600 km^2, providing detailed insights into base rates on hourly, daily, and monthly basis. We believe that using a widespread network of CPs, as we have done, is currently the most effective way to measure backcountry usage in hard-to-reach areas.

4.3 Bluetooth Low Energy

The beacon checker method has its limitations, being expensive and requiring substantial maintenance to provide consistent results over multiple seasons.

To address this, we have developed a new battery-powered device that continuously searches for BLE signals. The advantage of this method is that it requires no action from the skier, as most people carry at least one active BLE unit (e.g., phone, watch, or headset). The range of up to 100 m also ensures that it is possible to count multiple starting points where they converge within a 100 m band (which most common trips do at some point). The method will need to be validated using a time-lapse camera to determine the ratio of BLE signals to backcountry skiers (as for the CPs).

However, the main advantage is that it is much more cost-effective, with the material cost for one unit sits at around USD 250 compared to USD 1600 (excluding sales tax) for a CP with a beacon checker. Additionally, there is no need for maintenance during the season or a large vehicle with a trailer to transport the equipment.

4.4 Future work

To go from enumerating backcountry usage at the most frequented trailheads to estimating overall backcountry usage in the region, we need to determine what proportion of the total traffic our current studies are capturing with the CP and, in the future, with the BLE sniffers. One method to estimate this proportion is by analyzing a large database of GPS tracks (e.g. Toft et al. (2024)) to see what percentage of these activities originate at a CP. Once we know the proportion or ratio, we could compare our data with accident and fatality data to estimate the fatality rate of backcountry skiing in the region.

To measure a trend over time, we could monitor selected trailheads annually using either CP or BLE sniffers. By focusing on a few representative trailheads, the resources needed to maintain the project become more manageable.

5. CONCLUSION

We have reviewed and tested various methods to enumerate backcountry usage. Our first approach, using signaling data, would have considerable advantages if successful. Unfortunately, we found that the method was not as reliable as the preliminary findings suggested. Our second approach, using beacon checkers, was far more successful, enabling us to find the base rates of backcountry usage in Tromsø, Northern Norway, for the time of day, week, and month. In the future, we believe that the BLE counting devices will provide more flexibility and accuracy than the current network of CPs.

Our study not only demonstrates the use of different methodologies but also advances the understanding of the backcountry skiing population in Tromsø. By quantifying a large proportion of the overall population, we provide accurate and valuable data that can inform future decisions and policies.

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