Proceedings of the Estonian Academy of Sciences
2025, **74**, 2, 126–131

https://doi.org/10.3176/proc.2025.2.07

www.eap.ee/proceedings
Estonian Academy Publishers

LOGISTICS AND TRANSPORTATION

RESEARCH ARTICLE

Received 22 January 2025
Accepted 27 February 2025
Available online 4 April 2025

Keywords:
level crossing, micromobility, traffic modeling, estimation models, pedestrian safety

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Citation:
Jairus, T., Metlitski, S., Kask, M. and Kõrbe, K. 2025. Methodology for the measurement and estimation of pedestrian and cycle traffic at level crossings. *Proceedings of the Estonian Academy of Sciences*, **74**(2), 126–131. https://doi.org/10.3176/proc.2025.2.07

Methodology for the measurement and estimation of pedestrian and cycle traffic at level crossings

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ABSTRACT

Urban and suburban level crossings are critical intersection points between rail and pedestrian infrastructure, requiring careful monitoring and analysis of traffic patterns for safety and planning purposes. This paper presents a comprehensive methodology for measuring and estimating pedestrian and cycle traffic at urban and suburban level crossings. A dual-component system is introduced that considers separately regular crossing users and rail transport passengers, acknowledging their distinct temporal patterns. Three distinct temporal patterns were identified for both pedestrian movement and rail passenger flows through analysis of fixed counter data and passenger statistics, while a singular pattern was determined for cyclists. The methodology was validated at 14 railway crossings, establishing minimum requirements for measurement duration and optimal timing. The results indicate that counting periods of at least 24 hours are required, with optimal accuracy achieved during the spring and autumn months. This approach provides optimal resource usage for achieving adequate accuracy. Data collection and estimation supported by this framework will provide the grounds for evidence-based decision-making in railway crossing infrastructure planning and safety assessment.

1. Introduction

Railway level crossings are critical intersection points where rail and pedestrian infrastructure meet, requiring careful monitoring and analysis of traffic patterns for safety and planning purposes. These crossings are essential mobility nodes, where the quality of the infrastructure directly impacts both traffic safety and user convenience. The movement of pedestrians, cyclists, and other light traffic users across railway crossings inherently involves risks, which increase in proportion to train speeds and traffic volumes.

Current approaches to data collection and analysis vary significantly, often relying on short-term counts (STCs) without proper consideration of temporal variations. This lack of standardization makes it difficult to compare data across different locations and time periods, to take into account seasonal and daily variations in pedestrian and cycle traffic and to accurately project future traffic volumes. This, in turn, hinders evidence-based decision-making for infrastructure improvements.

The challenge is complex due to the dual nature of railway crossing usage: some users access train platforms as passengers, while others simply cross the railway as part of their journey. These two user groups exhibit different temporal patterns and respond to different influencing factors, necessitating a specialized approach to traffic analysis.

This paper presents a comprehensive methodology for estimating annual pedestrian and cycle traffic at railway level crossings based on STCs. The methodology addresses the need for standardized measurement and analysis processes to ensure data reliability and comparability. Our approach introduces a dual-component system that considers separately regular crossing users and railway passengers, acknowledging their distinct temporal patterns and providing specific conversion factors for each group.

2. Current situation

The analysis of pedestrian and cyclist movements at railway crossings has historically received less attention than vehicular traffic analysis. However, in contrast to the declining number of fatalities due to train-vehicle collisions at highway-rail level crossings, the number of pedestrian and cyclist fatalities at highway- and pathway-rail level crossings has remained relatively unchanged in recent years [1]. Over the last two decades, the number of vehicular collisions at level crossings in Estonia has decreased slightly, but the number of pedestrian injuries and fatalities has shown a slight increase [2]. This is not unique to Estonia, as similar trends have been noticed elsewhere, such as the United States [1] and Australia [3].

Accurate data on traffic volumes is an essential input for good planning in safety, as this indicates the actual exposure to risk and the possibility of conflict between traffic participants [4]. One of the main characteristics in transport planning is the annual average daily traffic (AADT). This parameter describes the number of vehicles passing a road section on an average day and is the basis for project selection, pavement design, capacity analysis, safety analysis, air quality analysis and more [5]. This value is usually gathered from permanent traffic counters (PTCs) or calculated from STC using PTC as a reference [6]. According to previous studies [7], most road administrations use expansion factors for converting STC results into AADT. This means that each STC will be assigned a reference PTC or an average PTC group. However, this approach has not been applied by the same road administrations to pedestrian and cycle traffic [8]. One reason against applying the exact same approach is the weather-induced variation in cycle traffic [9].

There have been studies using exercise apps as a data source, such as Strava [10], but the accuracy of this method relies highly on the penetration rate of a particular application. As demonstrated by others [11], this method is questionable with respect to the closed nature of such datasets. There have been estimation models with good accuracy for filling in the gaps in bicycle PTC data [12]. In similar fashion, the effect of the current infrastructure is estimated to have significant impact on both the volume and route choice of pedestrians and cyclists [13].

3. Methodology

The methodology developed for analyzing pedestrian and cycle traffic at railway crossings takes a systematic approach that considers the unique characteristics of these transportation nodes. Our approach recognizes that the use of a railway crossing comprises two distinct components: passengers accessing train platforms and users crossing the railway as part of their journey. This fundamental distinction forms the basis of our analytical framework, as these groups exhibit different temporal patterns and respond to different influencing factors.

While the actual counting is a rather straightforward process of counting people manually, determining the optimal time and length of the process was essential for obtaining good results. We used data provided by the Estonian railway operator AS Eesti Liinirongid (Elron) on station exits and entries, along with pedestrian and cyclist counts from Eco-Counter devices which rely on sub-surface induction loops and have a self-reported accuracy of 95%. Similar data have been widely adopted in current research [14–16].

The first phase was cleaning and validating the initial mobility dataset, as the raw data contained several anomalous instances of extremely high counts along with periods of inactivity. For this purpose, all data were loaded into a PostgreSQL database and validated via a hybrid approach where the data were visualized using Python and Matplotlib.

The second phase was creating virtual STCs for each location. A multitude of smaller datasets, ranging from one hour to one week, were extracted for each location, starting at each hour of the year. As a general reference, the yearly dynamics were calculated using hourly means of all valid data. Using this reference, the average daily traffic was calculated for every sub-dataset. The accuracy of each calculation was measured by comparing it to the actual average daily traffic of that location. The start time and length of each period were thus rated by the mean average relative error.

To determine more precise yearly reference curves, all locations were analyzed via k-means clustering. Finding the optimal number of clusters is essential for actual field counting, as there is no long-term reference related to that exact location. Therefore, three groups were clustered separately – pedestrians, cyclists and passengers.

The study area (Fig. 1) encompasses all authorized pedestrian crossings on the AS Eesti Raudtee infrastructure, providing a diverse sample across urban and rural contexts. This comprehensive coverage ensures that the methodology can address variations in usage patterns across different geographical and demographic settings. To develop and validate the methodology, we utilized multiple data sources, including passenger statistics from AS Eesti Liinirongid (Elron), fixed counter data from urban locations, and specifically conducted pilot counts using a hybrid approach. This approach combined manual counting from video recordings pre-processed by a custom computer vision solution based on the YOLO frame-

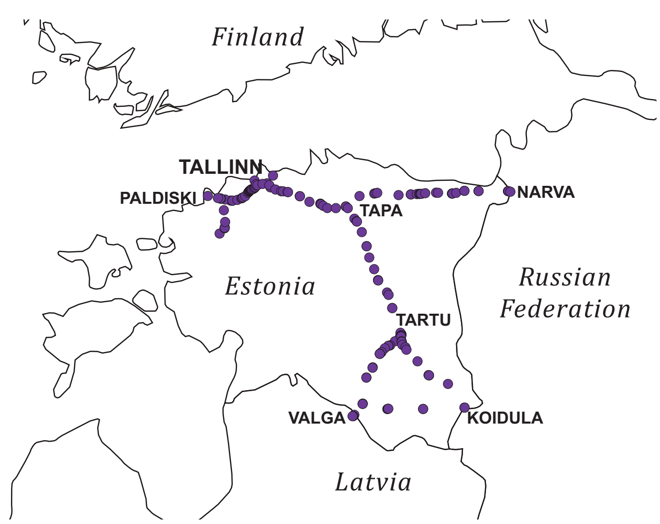

Fig. 1. Study area of the Estonian railway infrastructure.

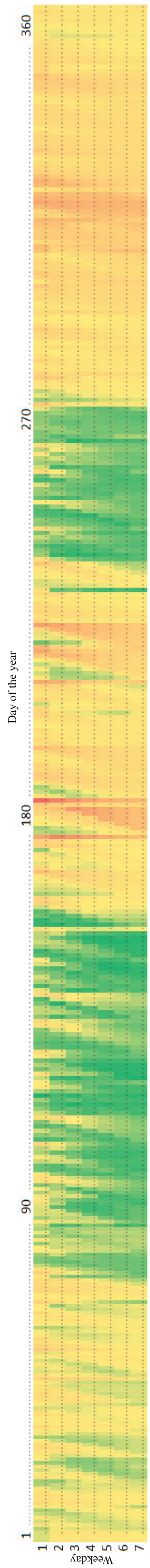

Fig. 2. Accuracy (average error, red is the highest, green the lowest) of predicted annual average traffic based on the counting length (y-axis, day of the week) and start time (x-axis, day of the year).

work [17] at 14 selected railway crossings. These data sources were complemented with demographic and spatial planning information to provide context for the observed patterns.

4. Results

The sub-dataset analysis yielded significant results about the optimal time and duration of STCs. As the variability of traffic changes over time, there are times when counting is always inaccurate. For example, during national holidays, the erratic nature of movements means that the average error is very high. Moreover, periods shorter than 20 hours provide inaccurate results and should be avoided when possible. Thus, the optimal counting period starts at 24 hours.

As shown in Fig. 2, longer periods do provide more accurate results, but the effect is less significant than choosing the right time. Considering the cost, a duration of more than a few days is not recommended. However, weekends should be avoided as the accuracy drops significantly. Seasonal pattern analysis identified optimal counting periods between 15 March – 15 May and 15 September – 15 November, when usage patterns are most suitable for calculating annual averages. Conversely, the summer school holidays (1 June – 31 August), the Christmas period (20 December – 10 January), and public holidays showed the greatest deviations from typical patterns. Our investigation into the requirements for counting duration demonstrated that 24-hour counts achieved 85% accuracy when compared to long-term averages, while extended five-day counts improved this accuracy to 92%. This finding highlights the importance of longer counting periods for reliable results, although we note that weekend counts showed significantly higher variability, with differences of up to 30% from weekday patterns. This variation emphasizes the need for separate weekend factors in locations where weekend traffic is significant.

The k-means clustering analysis confirmed three distinct patterns of weekly variation in passenger flows, each with unique characteristics and implications for traffic estimation, as shown in Fig. 3. Urban centers showed clear seasonal patterns with a 20–30% decrease in traffic during the summer. These locations also exhibited pronounced peak-hour patterns in line with typical work schedules. In contrast, suburban areas demonstrated the most consistent year-round usage, with strong morning and evening peaks but relatively similar patterns between weekdays and weekends. Rural locations presented a third distinct pattern, characterized by notable summer increases of up to 40%, less pronounced peak hours, and significant weekend variations. These three classes were also present in pedestrian traffic, showing the intrinsic relationship between walking and traveling by train based on conditions and needs.

However, cyclists (Fig. 4) do not follow those patterns. Due to the similarity of the pattern along the locations, the yearly dynamics of cyclists followed the same pattern across the classes and no separate clusters emerged. This reference dynamic was significantly different from the passenger and pedestrian traffic fluctuations, with a much larger amplitude and more pronounced high and low periods.

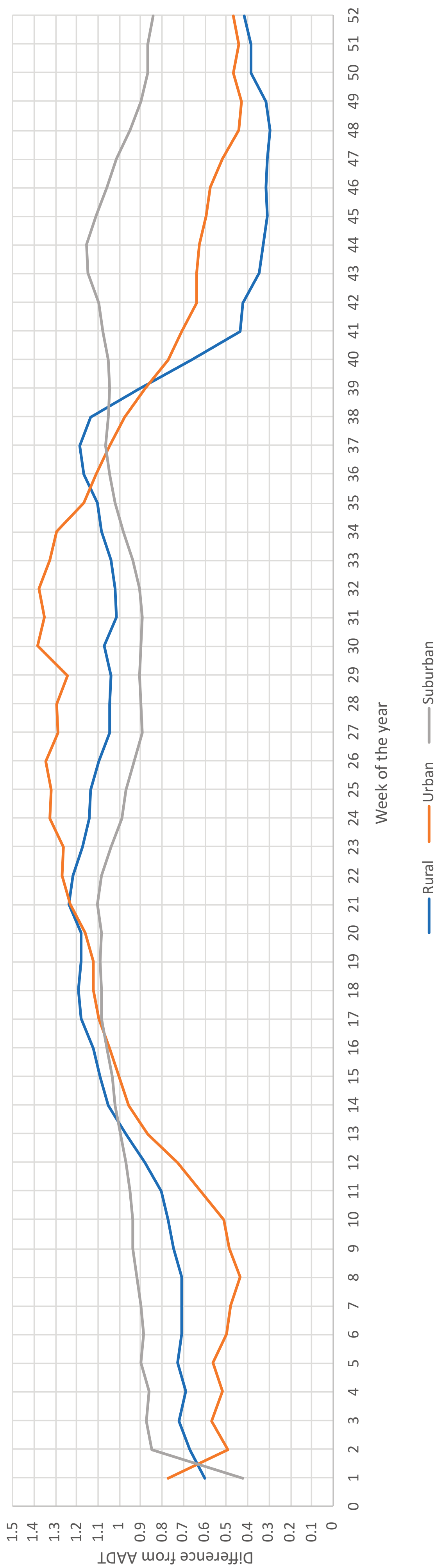

Fig. 3. Yearly fluctuations compared to yearly averages for different location types.

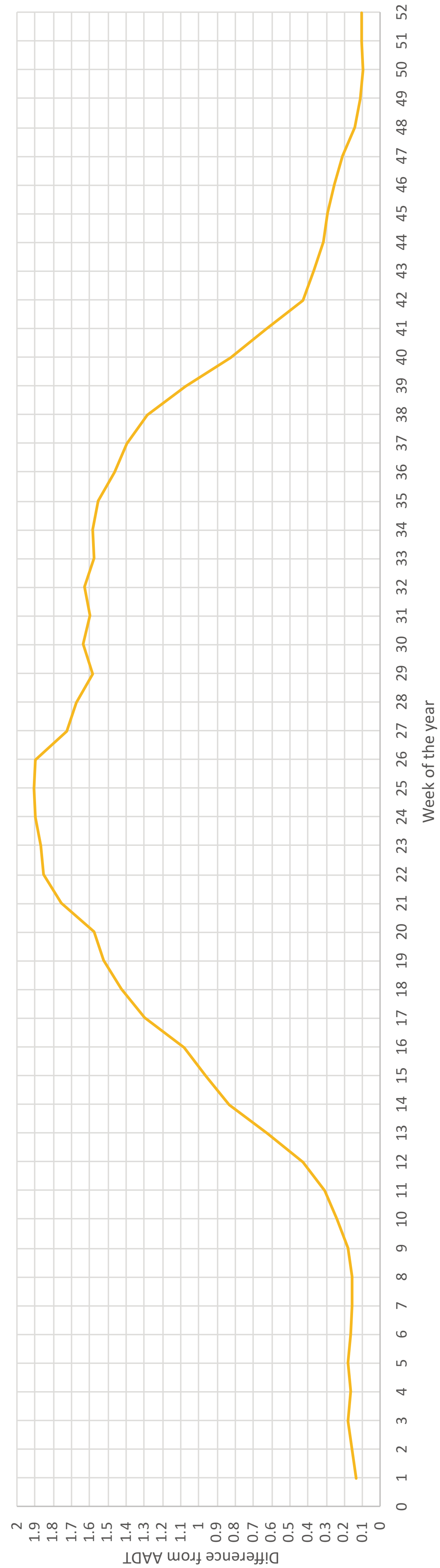

Fig. 4. Yearly fluctuations in cycle traffic.

Practical counting of varying length at 14 locations showed that extending the counting period beyond 24 hours did not provide significant change in the final result but would increase the cost of the process. Shorter counting periods enable the use of smaller batteries for the cameras and speed up the counting process.

5. Conclusions

The safety of cyclists and pedestrians at level crossings is of critical importance in the development of sustainable and active transportation systems. To develop safe and appropriate infrastructure, accurate and timely traffic volumes are necessary. Separation of railway passengers from regular level crossing users is an important element in improving the accuracy of estimation. These distinct user groups exhibit different temporal patterns and respond differently to various influencing factors, making their separate treatment essential for reliable results. This finding has significant implications for both infrastructure planning and safety assessment procedures, suggesting that current approaches that treat all pedestrian traffic as a single category may need revision.

The development of conversion factors for estimating annual traffic from short-term counts is a crucial component of the methodology. These factors are derived from analysis of long-term count data and take into account both seasonal and daily variations. Our analysis has revealed that a minimum of 24-hour counting is essential for reliable results. This requirement balances practical resource constraints with the need for reliable data. The identification of spring and autumn as the most representative periods for conducting counts provides clear guidance for planning data collection efforts, while the development of specific adjustment factors for other periods allow for year-round counting when necessary.

The validation of this methodology was conducted through pilot studies at selected railway crossings chosen to represent different contexts, including urban and rural locations, varying usage patterns, and different infrastructure configurations. These pilot studies provided valuable insights into the practical application of the methodology.

The implementation of this methodology will support evidence-based decision-making in infrastructure planning and safety assessment, while the identified future research directions will ensure its continued development and relevance. The adaptability of the framework to local conditions, combined with its standardized approach, makes it a valuable tool for transportation planners and safety analysts working with railway crossing infrastructure. Furthermore, this framework can be applied to different regions of the world, including other traffic participant groups besides cyclists and pedestrians.

Through the development and validation of this methodology for estimating annual pedestrian and cycle traffic at level crossings, we have established a robust framework that addresses a significant gap in transportation infrastructure planning and safety assessment. Our research demonstrates that accurate estimation of annual traffic volumes from short-term counts is feasible when appropriate temporal patterns and classifications are considered.

Data availability statement

All research data are contained within the article and can be shared upon request from the authors.

Acknowledgments

The authors gratefully acknowledge AS Eesti Raudtee for providing access to railway infrastructure, AS Eesti Liinirongid (Elron) for passenger statistics, and Teede Tehnokeskus AS for their technical support in data collection and validation. Their cooperation was essential for the successful completion of this study. The publication costs of this article were partially covered by the Estonian Academy of Sciences.

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Kergliiklejate loendusmetoodika raudteeülekäikudel

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Raudteeülekäigukohad on olulised ristumispunktid raudtee- ja kergliiklustaristu vahel, mistõttu on liiklusmahu ja selle dünaamika täpne ülevaade tähtis nii ohutuse kui ka planeerimise seisukohast. Artiklis tutvustatakse metoodikat jalakäijate ja jalgratturite liikluse mõõtmiseks ja hindamiseks raudteeülekäikudel. Metoodika koosneb kahest komponendist, mis eristavad regulaarseid ülekäigukoha kasutajaid ja rongireisijaid, arvestades nende erinevaid ajalisi mustreid. Statsionaarsete loendurite andmete ja reisijastatistika analüüsi põhjal tuvastati jalakäijate liikumises ja rongireisijate voogudes kolm mustrit, samas kui jalgratturitel ilmnes üks domineeriv muster. Metoodika valideeriti 14 asukohas, määrates kindlaks minimaalsed nõuded mõõtmise kestusele ja optimaalsele ajastusele. Tulemused näitavad, et täpse loenduse jaoks on vajalik vähemalt 24-tunnine mõõtmisperiood, kusjuures optimaalne täpsus saavutatakse kevad- ja sügiskuudel. Esitatud lähenemine tagab tõhusa ressursikasutuse piisava täpsuse saavutamiseks. Selle raamistiku toel kogutud andmed ja hinnangud loovad aluse tõenduspõhisteks otsusteks taristu planeerimisel ja ohutuse hindamisel.