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APPROACH FOR DETERMINATION DAILY PASSENGER TRAFFIC ON PUBLIC TRANSPORT USING SITE SURVEY FINDINGS

This paper outlines a methodology for analyzing data collected from site surveys to assess passenger flow on public transportation. To ascertain daily passenger volumes, it's necessary to manually or semi-automatically count the number of boarding passengers throughout the operational day. However, for a comprehensive public transport network with numerous routes, this approach demands a considerable workforce and incurs significant time and financial expenses. While visually surveying passenger flows offers the advantage of concurrently studying multiple routes, the daily values obtained through this method fail to account for the turnover rate on the trip. The paper introduces a methodology that combines two types of site surveys: passenger counts within the vehicle's interior and assessments of occupancy rates of the vehicles at selected city sites (public transport stops). The research demonstrates that conducting surveys within the vehicle's interior facilitates the acquisition of peak and off-peak turnover rates for both the direct and reverse directions of the route. Additionally, assessing passenger volumes at specific locations enables the determination of daily passenger flows in both directions during peak and off-peak periods. These obtained turnover rates are then applied to refine the daily passenger flow estimates for both directions of the route. The paper presents the utilization of the proposed methodology through a case study involving one of the bus routes operated by a private enterprise in Kryvyi Rih. Furthermore, the methodology underwent testing by comparing the daily passenger flow values for municipal bus routes, as determined by the proposed method, with the indicators from the operator's daily transaction reports for the same time frame. The disparity between the indicators falls within the range of 5 – 7%, suggesting the suitability and reliability of the proposed approach.

Keywords: passenger flow, public transport, turnover rate, passenger flow survey, transport modeling.

INTRODUCTION

Counting passenger traffic on public transport is crucial for effectively addressing urban mobility challenges and enhancing service quality for users of the transportation network [1].

Surveying passenger traffic on public transport routes in cities can be conducted through various methods, including [1, 3, 4, 5]:

in-vehicle surveys as counting passengers who board and alight at specific stops.

semi-automatic measurement utilizing mobile applications to record the number of passengers entering and alighting vehicles.

visual method with observing the changes in the frequency and occupancy of public transport vehicles throughout the day at selected sites, ensuring each route is observed at least once.

automatic measurement by installing door-mounted counters to track passenger entries and exits at stops, along with geolocation data.

collecting data from mechanical counters which are installed as barriers in transport terminals such as metro stations, railway stations, and bus stations.

gathering data from transaction reports from the tickets and subscriber cards.

In modern times, passenger traffic indicators (passenger flows), on public transport can be obtained through daily transaction reports provided by operators. These reports meticulously document each validation of transportation documents, such as tickets. In the city of Kryvyi Rih, a similar system is implemented called the Kryvyi Rih Resident Card [2]. However, in Ukrainian cities, contactless fare collection systems are predominantly utilized on municipal transport routes. Notably, contactless fare payment cards are not typically available on routes operated by private operators. In such scenarios, conducting field surveys emerges as a pertinent method for determining the volume of passengers transported on these routes. Field surveys are widely regarded as one of the most reliable means of collecting such data [3].

Passenger volumes serve as a starting point for assessing and making decisions in public transport. Additionally, when appropriate, these volumes serve as input data for transport modeling in specialized software such as PTV Visum [9], SUMO [10], and MatSim [11]. However, obtaining daily passenger flows presents significant challenges, as conducting comprehensive surveys within vehicle interiors throughout the day demands substantial human and financial resources. In large cities with extensive passenger transport networks, the cost of such counting escalates with the number of routes requiring surveying. Alternatively, measuring passenger flows at city locations traversed by public transport routes during the day necessitates fewer resources, enabling the simultaneous coverage of route groups. Nonetheless, this approach offers only a partial perspective of daily passenger flow on public transport.

ANALYSIS OF LITERATURE DATA AND FORMULATION OF THE PROBLEM

Numerous researchers have contributed to the methodological support of surveys on public transport passenger flows, aiming to address urban mobility challenges [3, 4, 7, 8]. They emphasize the advantages of manual counting methods, such as flexibility in selecting study locations and evaluation criteria, and the potential for obtaining high-quality site data. However, manual surveys are susceptible to the human factor, which may introduce bias and errors during data collection, and they often require a significant time investment and a large team of involved persons. To mitigate these challenges, some studies suggest the use of mobile applications [6] to count boarding and alighting passengers. This approach allows for tracking the vehicle's route and stop times, enabling verification of the data collector's work. Recording data in real-time poses a challenge as errors made by data collectors cannot be corrected once recorded. Automated passenger counting systems, which track entries and exits using dedicated counters, offer an advantage by accurately tallying passengers in real time, thereby minimizing the potential for human error. This method requires a stable mobile connection for transmitting traffic data. However, if turnstiles at transport terminals serve as counters, data collection is confined to specific locations within the transport network. Using cashless tickets for measuring passenger flows on public transport enables continuous data collection [1]. Nevertheless, the survey's quality relies heavily on passengers' honesty in confirming fare payment, sometimes necessitating additional monitoring.

Manual survey methods involving data collectors are regarded as one of the most precise approaches for collecting passenger flow data [3]. However, due to their high cost, these surveys are often constrained to a limited number of trips per day. To address this limitation, calculations are employed to extrapolate the data collected over shorter periods to estimate corresponding indicators for longer periods. This process involves utilizing coefficients of passenger flow variation, which account for changes in the number of carried passengers across different timeframes such as hours, days, weeks, months, or years. These coefficients are determined by comparing the maximum passenger flow capacity to the average capacity for the same timeframe [3].

Indeed, while progress has been made in converting specific passenger flow data into daily values, there remains an ongoing need to enhance the methodology for determining daily passenger flows on public transport. This is particularly relevant when relying on semi-automatic or manual in-vehicle surveys, as well as visual monitoring at key sites. Improvements in methodology are crucial for ensuring the accuracy and reliability of daily passenger flow estimates, thereby supporting effective decision-making and resource allocation within public transportation systems.

RESEARCH RESULT

The determination of daily public transport traffic volumes can be achieved through a combined survey approach, which involves assessing the level of vehicle occupancy along the route passing through designated study sites, as well as measuring the number of passengers boarding and alighting at specific public transport stops.

Surveys conducted at these sites aim to collect the following data [3]:

identification of the type of vehicle operating on the line;

evaluation of the occupancy rate within the vehicles;

determination of the actual headways along the study routes.

The assessment of the level of occupancy within vehicle interiors utilizes a widely recognized rating scale [3]:

1 point when less than half of the seats are occupied, indicating approximately a 30% occupancy rate;

2 points when more than half of the seats are occupied, suggesting approximately a 60% occupancy rate;

3 points when seats and half of the standing area are occupied, representing approximately a 75% occupancy rate;

4 points when the vehicle is full, but there is still room for additional passengers to enter, indicating approximately a 90% occupancy rate;

5 points when the vehicle is overcrowded, with no room for additional passengers, indicating a 100% occupancy rate.

Measurements within the vehicle are typically conducted once or twice a day during peak morning and evening hours. When implementing the proposed methodology, this survey is essential primarily to ascertain the turnover rate per trip:

$$k_p = {}^{Q_t}/_{Q_{max}} \quad (1)$$

Q_t; is the number of passengers transported in the relevant direction on the route, pers./trip.

Q_{max} denotes the maximum number of passengers in the vehicle during the trip in the same direction, pers./trip.

The turnover rate is calculated separately for the forward and return directions of the route. The coefficient with the higher value is designated as the turnover rate for the peak direction, while the coefficient with the lower value is considered the turnover rate for the off-peak direction.

The processing of the results from the survey of the level of occupancy within the vehicle at a particular site, typically a public transport stop, is conducted as follows. Given that the same route may traverse multiple sites, the criterion for selecting the passenger flow indicator is based on the maximum total flow in two directions (forward and backward) across all sites during the observation period (typically a working day):

$$q_l = \max\,(q_{dn} + q_{on}) \quad (2)$$

q_l is the maximum passenger flow among all sites, total for both directions of movement, based on the survey results at site n, pers./day;

q_{dn} is the passenger flow in the forward direction based on the survey results at site n, pers./day;

q_{on} is the passenger flow in the forward direction based on the survey results at site n, pers./day;

n signifies the survey site with the highest passenger flow in the sum of the two directions compared to other locations.

Passenger volume in each direction (forward and backward) is divided based on the level of occupancy: for peak hours with an occupancy rate of more than 60%, corresponding to a score of 3-5 points, and for off-peak hours with an occupancy rate of up to 60%, corresponding to a score of 1-2 points.

For each direction of traffic at the site, the number of passengers transported is calculated separately for the vehicle occupancy rate of 1-2 points and the vehicle occupancy rate of 3-5 points.

The total passenger flow on the route must align with the previously determined value of q_l:

$$q_l = q_{dp} + q_{dnp} + q_{op} + q_{onp} \quad (3)$$

q_{dp} is the passenger volume during the peak hour for the direct direction of the route, with an occupancy rate of 3-5 points;

q_{dnp} is the passenger volume during the off-peak hour for the direct direction of the route, with an occupancy rate of 1-2 points;

q_{op} is the passenger volume during the peak hour for the reverse direction of the route, with an occupancy rate of 3-5 points;

q_{onp} is passenger volume during the off-peak hour for the opposite direction of the route, with an occupancy rate of 1-2 points.

Despite conducting surveys at various sites throughout the working day, the determined passenger flow q_l cannot be regarded as the final value. This is because q_l represents only a single observation at a specific site. To convert this indicator into a daily passenger flow value, we will utilize the passenger volumes obtained from surveys conducted inside the vehicle.

The daily passenger flow in the forward direction of travel on the route can be determined as follows:

$$q_{ld} = q_{dp} \cdot k_{pp} + q_{dnp} \cdot k_{pnp} \quad (4)$$

Accordingly, the daily passenger flow in the opposite direction would be:

$$q_{lo} = q_{op} \cdot k_{pp} + q_{onp} \cdot k_{pnp} \quad (5)$$

k_{pp} is the turnover rate for the peak direction (the greater value of the two directions from observation in the vehicle);

k_{pnp} is the turnover rate for the off-peak direction (the smaller value of the two directions from the in-vehicle survey).

Then the daily passenger flow on the route will be determined based on the results of the combined survey:

$$Q_d = q_{ld} + q_{lo} \quad (6)$$

The implementation of this approach is shown in the example of the bus route of private operators (route taxi) number 3 in the city of Kryvyi Rih (Rozvylka - Kiltceva Square).

The passenger flows determined by the results of measuring the rate of occupancy of the interior of the route taxi during the working day are shown in Table 1. The study involved 10 sites during the working day, 5 of which were for the forward direction of the route, and 5 for the reverse direction. The largest passenger flow in terms of the sum of passenger flows in two directions among all sites was obtained for the location on 95th Square. Now it is necessary to determine the number of passengers transported for each of the directions for this location for the peak and off-peak hours of the day (3), using the appropriate survey forms (see Table 2).

Applying formulas (4-5) with the corresponding turnover ratios for the peak and off-peak directions, as determined by the results of the passenger flow in-vehicle survey, we can calculate the daily passenger flow for the two directions and the total passenger flow in the route.

The results of these calculations are presented in Table 3.

Table 1 – Results of the calculations: findings from analyzing passenger traffic during the survey at various sites

Research site	The volume of passengers, pass/day	Total passenger traffic in two directions, pass/day
Zhovten Cinema Stop in the direction of 44th quarter	2048	3623
Zhovten Cinema Stop in the direction of Rokovata Railway Station	1575	
Shakhtarska Str. in the direction of 173rd quarter	1819	3934
Shakhtarska Str. in the direction of KRES	2115	
95th quarter Square in the direction of O.Polia Sq.	2308	4202
95th quarter Square from O.Polia Sq.	1894	
Bus station in the direction of Dnipro Highway	1822	4196
Bus station in the direction of 95th quarter Square	2374	
Boarding school Stop in the diretion of Nebesna sotnia Str.	1248	2390
Boarding school Stop in the diretion of 17th quarter	1142	
Maximum passenger flow among all sites		4202

Table 2 – A portion of the survey form used at the site

Time	Transport mode	Route Number	Vehicle type	Assessing the occupancy rate
5:05	Bus	3	C	1
11:03	Bus	3	C	1
14:57	Bus	3	C	1
15:17	Bus	3	C	1
18:44	Bus	3	C	1

Table 3 – Results of the calculations: indicators of passenger flows

Route number	3
Direction 1	Rozvylka - Kiltceva Sq.

Direction 2	Kiltceva Sq. - Rozvylka
Indicator	**Value**
Passenger flow in the peak hour in Direction 1 (occupancy rate is more than 2)	1208
Passenger flow in the off-peak hour in Direction 1 (occupancy rate is 1-2)	1100
Passenger flow in the peak hour in Direction 2 (occupancy rate is more than 2)	834
Passenger flow in the off-peak hour in Direction 2 (occupancy rate 1-2)	1060
Total value	4202
Passenger turnover rate on a bus trip for the peak direction	2.54
Passenger turnover rate on a bus trip for the off-peak direction	1.58
Daily passenger flow in Direction 1	4806
Daily passenger flow in Direction 2	3793
Daily passenger flow (total)	8599

To validate the proposed approach, we compared the daily passenger flows for several municipal bus routes obtained using this methodology with the daily transaction reports of the operators for the same survey day. It's important to note that the operator's reports may not capture passengers who haven't validated their tickets.

The differences in passenger flow for bus routes 1a, 4 and 302 were 4%, for route 228 it was 5%, and for routes 228a and 1, it was 6%. Such minor differences indicate the adequacy of the proposed method and its potential application for processing passenger flow data obtained through the two survey methods described earlier, especially for routes lacking a cashless fare collection system, such as those operated by private operators.

DISCUSSION OF THE RESULTS OF THE STUDY

The results of calculating the daily passenger flow for one of the routes highlight that relying solely on one method of surveying passenger flows for public transport, whether it is counting passengers entering and exiting the vehicle at a stop or assessing the level of occupancy of the vehicle interior, may not yield reliable indicators. For instance, the total passenger flow which is determined from a survey at a particular site, even if chosen as the maximum value among all sites, may not consider the turnover on the route, which can be determined using in-vehicle study. In a specific example, the daily passenger flow on the route is determined to be 8599 passengers when considering both survey methods. However, when relying solely on the results of the survey at the site, the daily passenger flow is calculated to be 4202 passengers. This significant difference is attributed to turnover during the trip. Therefore, determining the daily passenger flow using both survey methods is deemed a more reliable approach.

SUMMARY

The proposed method for determining daily passenger flow on public transport applies to any type of vehicle and mode of transport. The obtained values can be verified using daily transaction reports provided by the operators, which are commonly implemented on public transport routes, or by automated measurement methods.

Daily passenger flows serve as vital indicators in urban passenger transport networks and can be further utilized in relevant transport models to validate the modeled results of public transport demand assignment [12].

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***В. Сістук.* Методика визначення добових пасажиропотоків на громадському транспорті на основі результатів натурних обстежень.**

Робота присвячена методиці обробці результатів збору показників пасажиропотоків на громадському транспорті, проведеного шляхом натурних обстежень. Для визначення добових показників пасажиропотоків необхідні вимірювання або у ручному або у напівавтоматичному режимі кількості перевезених пасажирів, проведені у салоні рухомого складу протягом робочого дня. Для мережі пасажирського транспорту із великою кількістю маршрутів подібні вимірювання потребують залучення значного числа обліковців та відповідних часових та фінансових витрат. Візуальний метод обстеження пасажиропотоків надає перевагу у вигляді можливості одночасного дослідження групи маршрутів, однак добові значення отриманих показників не враховують оборотність на маршруті. У роботі представлена методика визначення добових пасажиропотоків на громадському транспорті із використанням поєднання двох типів натурних обстежень: підрахунку пасажирів в салоні рухомого складу та оцінюванні рівня наповненості салону в обраних точках міста (зупинках громадського транспорту). У роботі показано, що обстеження у салоні рухомого складу дозволяє отримати пікові та непікові значення коефіцієнтів оборотності для прямого та зворотного напрямків маршруту. Вимірювання обсягів перевезень пасажирів на локації, у свою чергу, дозволяє визначити добові пасажиропотоки в обох напрямках руху для пікової та непікової години. Отримані коефіцієнти оборотності застосовуються для корегування добових пасажиропотоків для обох напрямків руху на маршруті. У роботі наведений приклад застосування запропонованої методики для одного з автобусних маршрутів приватного перевізника міста Кривий Ріг. Також методику перевірено шляхом порівняння визначених за методикою добових значень пасажиропотоків для маршрутів комунальних автобусів із показниками щоденних транзакційних звітів перевізника для цих маршрутів за той самий період часу. Розходження показників – у межах 5-7%, що говорить про адекватність методу, що пропонується.

Ключові слова: пасажиропотік, громадський транспорт, коефіцієнт оборотності, обстеження пасажиропотоку, транспортне моделювання.

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