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CHANGES IN PUBLIC TRANSPORT SERVICE DEMAND UNDER THE INFLUENCE OF SEASONAL COMPONENTS

Summary. *The article investigates the impact of seasonal components and other factors on the formation of demand for public transport services. The influencing factors are categorized into objective and subjective groups. Objective factors encompass economic, social, and environmental dimensions, with natural conditions, such as air temperature, weather fluctuations, and daylight duration, playing a decisive role in the emergence of seasonal variations in demand. Subjective factors include variables such as fare levels, the degree of comfort, accessibility of information, and the competitiveness of public transport relative to alternative modes of transportation.*

From a seasonal perspective, it is emphasized that passenger transport demand exhibits annual variability. In the summer months, demand typically declines due to school holidays, employee vacations, and the increased use of alternative means of travel. Conversely, during the colder seasons, demand rises, mainly due to adverse weather conditions and the necessity to cover greater distances under low-temperature conditions. Spring and autumn are generally characterized by relatively stable mobility patterns.

The required number of vehicles to ensure high-quality and comfortable transport services varies depending on user needs throughout the year.

Furthermore, it is essential to account for the specific urban context. In certain cities, public transport demand demonstrates lower seasonal fluctuation, even in summer, due to a high concentration of employment centers and cultural activities.

The primary objective of this study is to identify demand variations to ensure consistent and comfortable transport services within the framework of dynamic seasonal trends. The application of modern analytical methods is expected to enhance forecasting accuracy and support the development of more adaptive strategies for managing transport infrastructure. These improvements are anticipated to increase passenger satisfaction and foster long-term growth in public transport usage.

Key words: *public transport, passenger transport demand, conditions of the route network functioning, seasonal components, PTV Visum.*

1. INTRODUCTION

An essential precondition for the sustainable functioning of modern urbanized areas is the effective organization of public transportation. In the context of continuous urban population growth, increasing mobility, and the evolving transport preferences of residents, the need for accurate forecasting of passenger transport demand is becoming increasingly important. This enables the optimization of route networks and timetables, the rational allocation of vehicles across routes, and the maintenance of a high transport service level.

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However, when forecasting passenger flows, it is crucial to account not only for the constant objective characteristics of the transport system (e.g., service intervals, travel speed, infrastructure availability) but also for variable factors, among which the seasonal component plays a particularly significant role. Research findings indicate that seasonal fluctuations substantially impact the usage levels of public transport (PT) [1].

Passenger behavior tends to vary depending on the season, necessitating a flexible demand modeling approach. Modern forecasting methods increasingly incorporate seasonal factors in transport behavior models as key parameters. The application of various analytical approaches to assess changes in passenger flows, taking into account seasonal trends and peak load periods throughout the year, is particularly effective [2].

Thus, integrating the seasonal component into transport planning processes enhances the flexibility of management decisions, allows the PT system to better adapt to demand fluctuations, and contributes to forming a sustainable urban mobility model.

2. STATEMENT OF THE PROBLEM AND RELEVANCE OF THE STUDY

Seasonal variations, particularly weather conditions and vacation periods, significantly influence passenger behavior and their choice of transport mode. Research indicates that meteorological factors such as temperature, precipitation, and wind can considerably reduce or increase PT usage [3].

In addition, seasonal factors affect route congestion levels and necessitate adjustments to service schedules. Accounting for these fluctuations is critical for optimizing PT operations and ensuring the system's overall efficiency [4].

In the current context, applying modeling techniques to assess changes in passenger flows across different seasons is highly relevant for ensuring the effective functioning of PT systems. Incorporating seasonal variables into such models enhances the accuracy of forecasts and the efficiency of subsequent decision-making processes [5].

The aim of this article is to analyze and account for the impact of seasonal components on the modeling of passenger transport demand across different times of the year, intending to improve the route network of Lviv’s PT system.

The main objectives of the study are as follows:

- to analyze the impact of key factors, including socio-economic, technical, infrastructural, and seasonal elements, on the demand for transport services in the city of Lviv;
- to model the route network and analyze transfer probabilities, taking into account existing operational conditions of the PT system and seasonal variability in passenger flows;
- to evaluate the effectiveness of alternative strategies in route organization and vehicle fleet management aimed at enhancing the adaptability of the PT system to seasonal demand fluctuations and improving the quality of passenger services.

3. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Enhancing the quality of service for PT users is a primary indicator in assessing transport demand. Variations in passenger demand are driven by a wide range of interrelated factors [6].

Under modern urban conditions, ensuring the efficient operation of PT systems is emerging as a key element in the strategy for sustainable urban development. The increasing share of private transport, the transformation of employment structures, and growing expectations regarding service quality generate an objective need for flexible planning and optimization of PT route networks [7].

A central element of such planning is the forecasting of passenger transport demand, which not only enables the evaluation of the adequacy of transport supply but also facilitates adaptation of the system to changes in passenger behavior caused by introducing new routes, vehicle types, or schedule modifications. At the same time, accounting for seasonal demand fluctuations, which are cyclical and can significantly influence passenger flows, remains a crucial aspect [8].

Effective forecasting requires the consideration of several parameters, including the operational conditions of the PT system, the competitiveness of transfer routes compared to direct services, the role of transfer hubs with high passenger turnover, and the seasonal dynamics of passenger flows. Appropriate modeling allows for the development of techno-economic justifications for the number of transport units assigned to routes, meeting the average annual demand and seasonal variations.

Thus, integrating the seasonal component into the transport planning process provides a foundation for effective managerial decision-making, aimed at improving service quality, reducing congestion on route networks, and ensuring their balanced development.

Transport service demand is defined by the nature and quantity of spatial linkages between service providers and users. Specific transport needs arise based on the spatial distribution of potential demand points. In most cases, proper organization of transport services requires field studies, which are often time- and resource-intensive [9].

According to the study in [10], the number of trips made by individuals is directly linked to the various needs of the population, such as commuting for education or employment (which tend to be regular), as well as travel for cultural or recreational purposes.

The authors in [11] propose a set of demand management measures to ensure optimal performance of PT systems (see Table 1).

Table 1

Measures for managing transport demand [11]

Expansion of Alternatives for Public Transport Mobility	• Improvement of PT services • Enhancement of bicycle traffic infrastructure • Mobility management programs • Dedicated bus lanes • Car rental services • Commute-to-home programs • Bicycle-sharing service
Economic Measures	• Toll roads • Increase in parking fees • Increase in fuel tax • Incentives for transit use
Land-Use Optimization Policy	• Rational urban development • Parking regulation • Car-free planning • Traffic calming • Transport planning reforms
Other Programs	• Rational land-use development • Parking regulation • Car-free planning • Traffic calming • Transport planning reforms

Urban mobility can be classified according to various purposes: commuting to work, educational travel, shopping, etc. [12–14]. Study [15] examines the characteristics of shopping trips, which significantly impact urban transport flows, although less frequent than commutes to work or educational institutions. Research [16] establishes the relationship between socio-demographic characteristics, residential location choice, and the timing of shopping activities.

Studies by various authors identify a range of measures that can contribute to the improvement of PT services, including:

– reliable, comfortable, and convenient vehicles [17];
– providing additional advantages compared to private cars (e.g., lower cost and travel time) [18];
– adjustments to vehicle schedules and frequencies on routes [19];

– enhanced information provision for users, especially at stops [20];
– effective management of seasonal peaks in demand [21].

These measures improve service quality and significantly enhance the operational efficiency of the transport system, ensuring more comfortable and economically advantageous travel for passengers.

Seasonal fluctuations in transport demand are a crucial factor to consider in modeling and planning PT networks. Demand variations may be associated with different seasons and specific events characteristic of certain periods (e.g., holidays, festivals, school breaks) [22, 23].

Research indicates that demand in winter may be influenced by weather conditions such as snowfall and low temperatures, which reduce the attractiveness of alternative modes like cycling or walking. Conversely, in the summer, transport demand often declines due to vacations and holidays, when some population is away from the city [24].

Seasonal changes in PT demand can also be driven by tourism flows or the start of the academic year, which increases the number of students and schoolchildren using PT services [25].

Contemporary studies emphasize that implementing adaptive traffic management systems, such as dynamic scheduling, can help mitigate the effects of seasonal demand fluctuations. These systems can adjust headways based on actual demand at specific times of the day or year, thereby improving network efficiency and reducing operational costs [26].

According to recent research, demand forecasting systems should integrate large-scale data sources (e.g., GPS data, mobile applications) to anticipate seasonal shifts better and adjust transport strategies in line with population needs. GPS data enables tracking of real-time vehicle movements and identification of the most congested routes. At the same time, mobile apps help collect up-to-date information on user behavior and transport preferences. These approaches contribute to more precise logistical planning and support more flexible traffic flow management [27].

Transfers are also a critical component of urban transport systems, influencing the demand for passenger services. Numerous academic studies explore various aspects of transfers, including time costs and psychological and economic factors that shape passenger behavior.

As shown in several studies, an increased number of transfers typically leads to reduced transport service demand. When more than two transfers are required, passengers often choose more direct routes, even if they are more expensive or less comfortable. This phenomenon is particularly relevant under time constraints and high competition with other modes of transport, such as cars or taxis [28].

When passengers can choose between a direct route and one involving transfers, the likelihood of selecting the latter largely depends on the expected time savings. A combined model (Equation 1) [29] has been applied to describe this phenomenon, reflecting how the probability of choosing a transfer route varies as a function of time saved.

$$y = 0.01 \cdot x^{0.07} \cdot e^{0.1 \cdot x}, \qquad (1)$$

where x – denotes the time savings (in minutes) when using a route with a transfer.

The authors of the study [30] emphasize the challenges of obtaining reliable real-time input data, particularly regarding passenger behavior. They propose a modeling approach based on simulation techniques and aggregated statistical indicators. Special attention is given to the effects of seasonality, weather conditions, and the socio-economic situation in the region.

Approaches to adapting PT schedules to fluctuations in demand are addressed in the study [31], which describes the effectiveness of implementing dynamic timetables generated from data obtained through mobile applications, GPS navigation, and similar technologies.

In study [32], the impact of the development of the “Mobility-as-a-Service” (MaaS) concept on demand structure is analyzed. It has been demonstrated that integrating various transport modes (e.g., buses, trams, bike-sharing, and taxis) into a unified digital platform increases the attractiveness of PT and reduces population dependence on private cars.

Thus, contemporary academic research aims to construct comprehensive forecasting models that consider a wide range of factors, from transport infrastructure and technical characteristics of vehicles to user behavior and their interaction with digital services.

4. RESEARCH RESULTS

The PTV Visum software environment was utilized to analyze the characteristics of the route network and conduct subsequent modeling. The developed transport model of Lviv includes 3.045 nodes (i.e., intersections) and 8.442 road segments, with a total length of 1.757 km. The urban network comprises 62 routes (with a combined length of 822 km) and 950 stops. The entire modeled area is divided into 89 transport zones. The zoning was carried out based on the recommendations of the Department of Transport and Communications of the Lviv City Council, taking into account population density and the distribution of PT stops.

A base origin-destination matrix was developed based on survey data and population mobility indicators. The total daily number of trips is 967.000. Out of 7.832 possible pairs of transport zones, 1,410 lack direct PT connections, indicating a baseline transfer necessity rate of 0.18.

A four-stage transport demand model was employed to assess passenger interchange at PT stops, disaggregated by passenger actions (boarding, alighting, transfers at the same or nearby stops). The redistribution of trips was conducted in three phases: determining time intervals, route generation and selection, and load assessment.

The seasonal component significantly impacts the variability of PT demand. In Lviv, as in many other cities with pronounced seasons, passenger flow volumes exhibit regular fluctuations throughout the year. These variations are driven by both natural (weather conditions) and social factors (school load, tourist activity, holidays, etc.).

A comparative analysis of passenger numbers across different seasons was conducted to evaluate the influence of weather conditions on PT demand in Lviv (Fig. 1). Data were collected from the city's PT GPS and mobile trip planning applications.

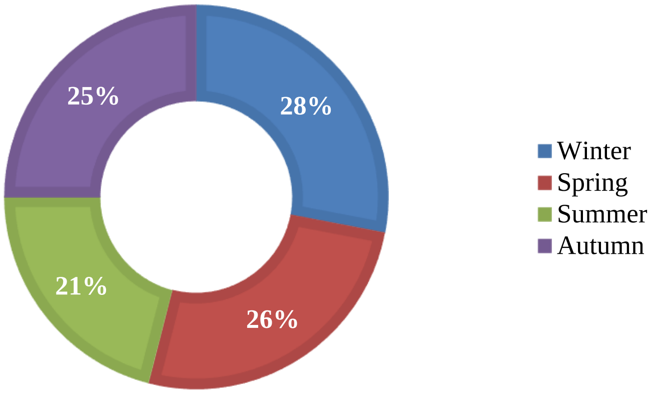

Fig. 1. Passenger transport demand across different seasons
(based on data from the city's PT GPS and mobile travel planning applications)

Seasonal fluctuations in PT demand in the city of Lviv indicate a significant increase during the winter months, primarily due to adverse weather conditions limiting private vehicle use. Additionally, December experiences a seasonal spike in travel volume in the lead-up to the holiday period. On average, when temperatures drop below –10 °C or when there is heavy snowfall, the number of PT users can increase by 30–40 %. Negative weather conditions, such as snow, rain, and low temperatures, discourage residents from taking long walks and reduce bicycle usage. According to data provided by the Lviv Department of Transport, the average number of PT passengers increases by 15–20 % compared to other seasons.

Spring and autumn represent transitional periods. Demand remains high in March and April; however, with warmer weather in May, passenger flow begins to decline, particularly due to the end of the academic semester. Studies show that during these periods, the number of PT users decreases by 15–20 % compared to winter, depending on the time of day. September is traditionally marked by a sharp increase in demand due to the beginning of the academic year, leading to a rise in trips by students, schoolchildren, and educational staff. During this time, routes serving universities and dormitories experience particularly high loads.

During school breaks, demand decreases by 10–15 % compared to autumn or spring levels. In September, the number of passengers on PT routes reached approximately 110.000; during holidays, it dropped to around 95.000.

During the academic period, demand for PT remains consistently high, especially in the morning and evening hours, as students and pupils travel to and from educational institutions. In summer, the number of passengers decreases due to school holidays. In contrast, during the winter break, demand slightly drops due to the absence of students and schoolchildren from the transport system.

Fig. 2 illustrates the variation in transport demand depending on temperature levels. The diagram represents specific temperature values (ranging from –10 °C to +20 °C in 5 °C intervals) and shows demand changes under various thermal conditions. Demand peaks at colder temperatures, then decreases toward zero at around 0°C. As the temperature increases to +10°C, a slight rise in demand is observed again. The highest demand is recorded in the -5 °C to -10 °C range, indicating an increased reliance on PT in cold weather conditions (see Fig. 2).

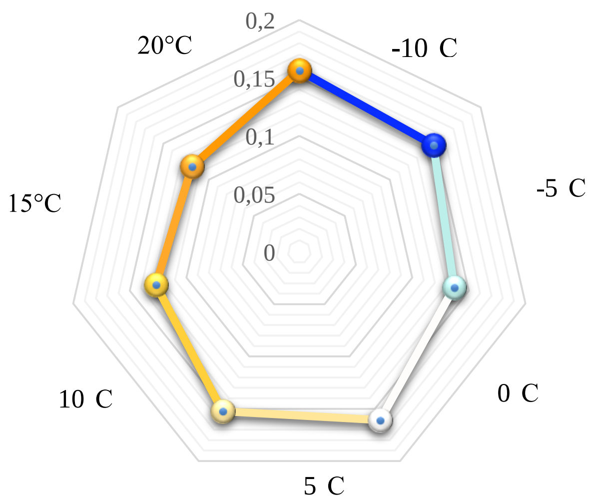

Fig. 2. Seasonal variations in travel demand depending on temperature conditions

Mobility growth can be temporary, during holidays or mass events, or long-term, due to urbanization, urban planning transformations, or economic development.

Seasonal variations in demand significantly affect the functioning of the route network. The main factors considered in the analysis include waiting time, transfer time, and total travel duration.

Detailed operational performance indicators of the system are presented in Table 2. In the simulation of Lviv's route network, data derived from empirical studies were incorporated into the software, allowing the model to reflect real-world traffic conditions and adapt to the specific characteristics of the urban environment. Based on seasonal variations in travel demand, seasonal PT operating scenarios were modeled using different passenger behavior models, primarily based on average waiting times.

PT operations during the spring and autumn correspond to a standard scenario with a stable demand level. The summer season reflects a period of reduced demand. In contrast, the winter season corresponds to peak demand conditions, during which PT must provide adequate service while considering network congestion, environmental constraints, and urban comfort.

Table 2

Operational parameters of Lviv's route network (based on PTV Visum modeling)

No	Value	Measured value
1	Total number of passenger trips using PT	903660
2	Average trip distance, km	8,3
3	Average trip duration, minutes	36
4	Average transfer waiting time, minutes	15,4
5	Average initial waiting time at the stop, minutes	17,8
6	Average walking time between stops during transfers, minutes	1,4
7	Number of passengers making a transfer	308860
8	Share of passengers making one transfer, % of total PT trips	33

Passengers typically rate spring and autumn service conditions as "good." During these periods, average waiting times do not exceed 10–15 minutes. This scenario is characterized by moderate network load, allowing operators to adjust service intervals to optimize costs while maintaining average waiting times within 15–20 minutes.

The winter period places the greatest strain on the urban transport system. Insufficient PT service and increased demand can lead to higher private vehicle usage. To prevent this, PT should operate with minimal headways, ensuring passenger waiting times of up to 5 minutes.

Improvement of the route network requires analysis of several key parameters, including travel duration, potential delays based on network load, and anticipated changes in passenger behavior.

Regardless of the season, passengers make decisions based on a combination of factors influencing their transport mode choice – a process known as modal choice. Four main approaches are used to evaluate it: rational, socio-geographic, socio-demographic, and socio-psychological. The rational approach is based on key indicators such as travel time and cost. The socio-geographic approach considers population density, land use, and spatial organization. The socio-demographic approach focuses on user characteristics such as age, gender, and employment status. The socio-psychological approach considers lifestyle, habits, and individual preferences. A combination of these factors allows for constructing a more accurate model of transport mode decision-making.

Since this study focuses on the case of Lviv, it is essential to consider specific local characteristics of the urban PT system that may influence the reliability of the obtained results:

– the city lacks any routes with a fully dedicated PT lane along their entire length. While there are separate segments on major streets with dedicated lanes, they are insufficient to ensure a systemic impact on the network's operation;
– only 10 % of PT stops are equipped with electronic arrival boards, significantly influencing passengers' perception of waiting time.

Table 3 presents the projected travel demand within the route network, modeled travel characteristics, and corresponding network parameters across different seasons (based on Table 2 data).

During the summer period, the likelihood of choosing a route with a transfer remains low if the time savings are less than 20 minutes. However, a sharp increase in this probability is observed when the time savings exceed this threshold: within 20 to 40 minutes, the likelihood rises from 10 % to 70 %.

In the spring-autumn period, the probability of choosing a transfer route decreases compared to the summer and is estimated at 0.32 (according to Equation 1). However, when fixed-schedule methods are implemented, the probability of transfers increases. This is attributed to the fact that users tend to prefer the transfer option when the waiting time for a direct route is considerable and the transfer timing is known or predictable.

In winter, the lowest probability of transfers is recorded – 0.27. With shorter headways, passengers are inclined to choose the transfer option only when it leads to substantial time savings, as waiting times at stops are minimal. Such situations are relatively rare within the current configuration of Lviv's route network.

Table 3

Operational parameters of Lviv's route network across different seasons (based on PTV Visum modeling)

Value	Indicator values across different seasons		
	Winter	Autumn/spring	Summer
Total number of passenger trips using pt	1357890	912140	728468
Average trip distance, km	9.0	9.5	9.8
Average trip duration, minutes	31	38	47
Average transfer waiting time, minutes	2.64	6.5	11.3
Average initial waiting time at the stop, minutes.	2.4	13.3	19.1
Average walking time between stops during transfers, minutes	1.2	1.5	2.3
Number of passengers making a transfer	342540	274598	343244
Share of passengers making one transfer, % of total pt trips	27	32	49

Table 4 presents the calculated number of transport units required for the efficient operation of the network, based on projected demand and the proposed conditions. Modeling was conducted under two scenarios: the first scenario reflects the current route distribution, in which 65 % of routes are served by medium-capacity buses and 35 % by high-capacity buses; the second scenario assumes an increase in the share of routes operated by high-capacity buses to 50 %.

Table 4

Calculation of the required number of vehicles for the operation of Lviv's route network across different seasons

Value	Winter	Autumn/spring	Summer
Current distribution by vehicle type			
Number of high-capacity buses (passenger capacity – 110)	242	186	143
Number of medium-capacity buses (passenger capacity – 42)	187	176	117
Number of trams (passenger capacity – 160)	86	51	38
Number of trolleybuses (passenger capacity – 106)	96	57	44
Scenario: increased share of high-capacity buses on bus routes			
Number of high-capacity buses (passenger capacity – 110)	269	187	54
Number of medium-capacity buses (passenger capacity – 42)	163	127	73

The implementation of such measures will significantly improve the quality of transport services. It will also allow for consideration of the technical characteristics of vehicles, particularly their passenger capacity, in route deployment planning.

5. CONCLUSIONS AND RESEARCH PERSPECTIVES

1. The study of Lviv's PT route network highlights the importance of a comprehensive approach to its improvement, considering socio-economic, technical, and organizational aspects that affect system efficiency. Seasonal fluctuations in demand – particularly the decline in summer and increase in winter – must be accounted for in route planning and adaptation.
2. The transport demand analysis revealed that numerous factors influence user choice, including waiting time, transfer convenience, travel time savings, and weather conditions. Passenger transport demand in winter accounts for 28 %, in autumn and spring – 25 % and 26 % respectively, and in summer – 21 %. During winter, when weather conditions complicate travel,

passengers prefer more reliable and stable routes, emphasizing the need to adjust service schedules to seasonal changes.

3. Accounting for seasonal demand variations allows for better distribution of passenger loads, particularly at transfer hubs during peak periods. The probability of transfers in winter is 0.27 due to shorter headways, and transfers occur only with significant time savings. In autumn and spring, this probability rises to 0.32. In summer, the likelihood of transfers increases substantially with longer waiting times, from 10 % at 20 minutes to 70 % at 40 minutes.
4. Analysis of the existing routes and urban infrastructure indicates the need to increase the share of high-capacity buses and improve stops and transfer hubs, which would help reduce pressure on central areas. Considering seasonal peaks, especially in winter, will optimize vehicle allocation and reduce overcrowding. The required number of vehicles to operate Lviv's route network is estimated at 611 units for winter, 470 for autumn/spring, and 342 for summer. Proposed improvements, including adaptive scheduling and enhanced passenger information systems, could significantly improve service quality and positively influence demand. Seasonal variations in ridership must be considered when planning service frequency, launching or canceling additional trips, adjusting vehicle numbers during peak hours, and modeling demand distribution for route load balancing.
5. The research concludes that a strategy focused on passenger comfort and travel speed, combined with advanced modeling and demand analysis methods, can substantially improve Lviv's route network operation. Including seasonal demand changes is crucial for adapting the network to varying conditions throughout the year.
6. Further research should aim to enhance passenger flow forecasting methods, adapt the network to dynamic conditions, and develop intelligent transport systems capable of real-time passenger flow management. Additionally, attention should be given to seasonal trends, which are essential in designing strategies to improve transport service quality under changing weather and economic conditions.

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ЗМІНА ПОПИТУ НА ПОСЛУГИ ГРОМАДСЬКОГО ТРАНСПОРТУ ПІД ВПЛИВОМ СЕЗОННОЇ КОМПОНЕНТИ

Анотація. *У статті розглянуто вплив сезонної компоненти та інших чинників на формування попиту на послуги громадського транспорту. Чинники, які впливають на попит, поділяють на об'єктивні та суб'єктивні. До об'єктивних належать економічні, соціальні та природні аспекти, серед яких саме природні умови (температура повітря, погодні зміни, тривалість світлового дня) відіграють ключову роль у формуванні сезонних коливань. До суб'єктивних зараховують такі параметри, як вартість проїзду, рівень комфорту, доступність інформації та конкурентоспроможність громадського транспорту порівняно із іншими видами перевезень.*

У контексті сезонності підкреслено, що попит на пасажирські перевезення змінюється протягом року: влітку, наприклад, він знижується через канікули, відпустки та використання альтернативних засобів пересування, тоді як у холодні місяці – навпаки, зростає, зокрема через несприятливі погодні умови та необхідність пересуватись на великі відстані в умовах низьких температур. Весна і осінь характеризуються стабільним попитом на переміщення. Необхідна кількість транспортних засобів, для забезпечення якісного і комфортного проїзду змінюється відповідно до потреб користувачів транспортних послуг.

Водночас варто враховувати й специфіку різних міст. У деяких містах попит на громадський транспорт може змінюватися менше навіть у літній період через високу концентрацію робочих місць та культурних подій.

Основна мета дослідження полягає у визначенні зміни попиту для забезпечення стабільного та комфортного транспортного обслуговування в умовах змінної сезонної динаміки. Використання сучасних аналітичних методів дасть змогу підвищити точність прогнозування та розробити гнучкіші стратегії управління транспортною інфраструктурою. Це сприятиме підвищенню рівня задоволеності пасажирів і, відповідно, зростанню попиту на громадський транспорт у довгостроковій перспективі.

Ключові слова: *громадський транспорт, попит на пасажирські перевезення, умови функціонування маршрутної мережі, сезонні компоненти, PTV Visum.*