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Cost-effective Urban Transport Planning under Seasonal Tourism Demand: Evidence From Barcelona Using GTFS and Official Tourism Statistics

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Abstract

Urban public transport systems in tourism-intensive cities face distinctive challenges in managing service provision under substantial seasonal demand variations. While tourism generates significant temporal fluctuations in mobility needs, conventional transport planning typically prioritizes service stability over demand-responsive adjustments. This study examines the relationship between seasonal tourism demand and urban transport service provision in Barcelona, assessing alignment patterns and cost-effectiveness implications across different seasonal periods. The analysis integrates standardized General Transit Feed Specification data with official tourism statistics covering 2017 through 2019 and 2023 through 2025, enabling systematic assessment of how transport service intensity responds to predictable tourism seasonality. The empirical findings reveal substantial misalignment between demand and supply patterns. Foreign hotel overnight stays vary by more than threefold between high and low seasons, while scheduled transport services differ by less than four percent across the same periods. This divergence generates marked seasonal variation in cost-effectiveness, with service provision per unit of tourism demand varying threefold between peak and off-peak periods. During high season months, elevated tourism demand encounters largely stable service levels, creating capacity pressures and reduced cost-effectiveness. During low season months, tourism demand contracts substantially while service provision remains constant, resulting in underutilized capacity and elevated cost-effectiveness ratios. The study constructs a reproducible analytical framework combining open-access transit and tourism data to evaluate seasonal planning patterns without requiring proprietary operational cost information. The findings suggest that modest seasonally adjusted service strategies could improve both efficiency and service quality in tourism-intensive urban contexts.

Keywords: Barcelona, Cost-effectiveness Analysis, GTFS Data, Tourism Seasonality, Urban Public Transport.

Introduction

Urban public transport systems in major tourist cities face a distinctive challenge: managing operational efficiency while accommodating substantial seasonal fluctuations in passenger demand driven by tourism flows (1–4). These fluctuations create temporal mismatches between service supply and actual demand, potentially reducing cost-effectiveness during both peak and off-peak periods (5–7). While transport authorities typically design service levels to meet baseline resident demand with some additional capacity for visitors, the magnitude of seasonal tourism variation in many cities raises questions about whether conventional planning approaches adequately balance service quality with operational efficiency (8–10). The integration of tourism demand dynamics into urban transport planning has received growing attention in the smart city and sustainable mobility literature (11). However, most existing studies treat tourism as a static variable or focus exclusively on infrastructure capacity rather than service-level adaptations (12, 13). Few empirical investigations systematically examine how the temporal distribution of transport supply aligns with seasonal tourism patterns, or assess the cost-effectiveness implications of maintaining relatively invariant service levels throughout the year (14, 15). This gap is particularly significant given the increasing availability of standardized, open-access transport data through formats such as the General Transit Feed Specification (GTFS), which enable precise measurement of service intensity and temporal availability across different seasons.

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Barcelona presents an ideal case for examining these dynamics. As one of Europe's most visited cities, Barcelona experiences pronounced seasonal tourism patterns while maintaining a sophisticated, multimodal public transport system (16, 17). The city's transport planning operates within a mature institutional framework and benefits from comprehensive data infrastructure, making it possible to conduct rigorous empirical analysis of the relationship between tourism demand and transport service provision (1, 8). Moreover, Barcelona's position as a recognized smart city leader provides broader relevance for understanding how data-driven approaches can inform adaptive transport planning in tourism-intensive urban environments (8, 18).

This study addresses the gap between tourism demand dynamics and urban transport supply by analyzing seasonal variations in both tourism intensity and public transport service levels in Barcelona. Drawing on GTFS data and official tourism statistics covering the period 2017 to 2025, we examine how transport service supply responds to seasonal tourism fluctuations and assess the cost-effectiveness implications of current planning approaches. The analysis constructs a relative cost-effectiveness index that relates service supply to tourism demand, enabling comparison across high and low tourism seasons without requiring detailed operational cost data.

The study is guided by four interrelated research questions:

This study addresses four interrelated research objectives. First (RQ1), it examines how seasonal tourism demand affects the intensity and temporal distribution of urban public transport supply in a major tourist city. Second (RQ2), it assesses whether current urban public transport services are aligned with tourism-driven demand during peak and off-peak seasons. Third (RQ3), it evaluates how the cost-effectiveness of urban transport provision differs between high and low tourism seasons. Fourth (RQ4), it considers the extent to which seasonally adjusted transport planning could improve service efficiency without increasing operational costs.

The remainder of this paper proceeds as follows. Section 2 reviews relevant literature on tourism-transport interactions and seasonal demand management in urban mobility systems. Section 3 describes the data sources, seasonal classification approach, and analytical methods employed. Section 4 presents empirical findings on seasonal patterns in tourism demand, transport supply, and cost-effectiveness. Section 5 discusses the implications for urban transport planning in tourist cities, and Section 6 concludes with policy recommendations and directions for future research.

Extant scholarship on tourism–transport interactions has established that international visitor generate concentrated spatiotemporal demand patterns that differ fundamentally from resident travel behaviour (19–22), while the overtourism literature has documented how peak-season congestion strains urban infrastructure in major tourist destinations such as Amsterdam and Dubrovnik (23–26). Notwithstanding this growing body of evidence, the predominant analytical emphasis has centred on spatial accessibility and infrastructure capacity constraints rather than on dynamic, season-driven service-level adjustments (14, 27). Research on seasonal demand management in public transport has focused on intra-daily and intra-weekly fluctuations rather than inter-seasonal planning horizons (28–32), and demand-responsive methodologies while theoretically promising to remain largely untested at this temporal scale (33–36). The progressive adoption of the General Transit Feed Specification (GTFS) as an international standard has created important methodological possibilities for rigorous temporal service analysis (3, 37–40). However, its integration alongside official tourism statistics to assess seasonal supply demand alignment remains underexplored (41–44). From an economic efficiency perspective, conventional transport cost-effectiveness frameworks rely on operational expenditure data reported only at aggregate levels (45–47).

The foregoing synthesis reveals several interconnected gaps that this study addresses. First, while tourism impacts on urban infrastructure are widely acknowledged, empirical analysis of how scheduled transport services respond to predictable seasonal tourism variations remains limited. Second, despite advances in demand-responsive transport theory, the application of adaptive service principles to tourism-intensive urban settings has received insufficient empirical attention. Third, although GTFS enables precise measurement of service provision, its integration with tourism statistics for seasonal alignment assessment is underdeveloped. This study bridges these gaps by constructing a relative Cost-Effectiveness Index (CEI) that relates GTFS-derived service supply metrics to official tourism demand data, providing a reproducible analytical framework applicable without proprietary cost information.

Methodology

This study employs a quantitative approach to examine the relationship between seasonal tourism demand and urban public transport supply in Barcelona. The methodology integrates standardized transit data with official tourism statistics to assess service-level alignment and cost-effectiveness across different seasonal periods. The research design emphasizes reproducibility through the use of open-access data sources and transparent analytical procedures.

Study Area and Case Selection

Barcelona (approximate GPS coordinates 41°23′ N, 2°11′ E) serves as the empirical setting for this investigation. The selection of Barcelona as the study area is justified by several characteristics that make it particularly suitable for examining tourism-transport interactions. The city ranks among Europe's most visited destinations, receiving approximately 12 million international overnight visitors annually before the pandemic and demonstrating pronounced seasonal tourism patterns with clear peak and off-peak periods. Barcelona's public transport system represents a mature, multimodal network encompassing metro, bus, tram, and regional rail services, all integrated under a unified fare structure and planning authority. This integration enables comprehensive analysis of urban transport provision without the complications of fragmented governance structures.

The city's positioning as a recognized smart city leader provides additional relevance for the study. Barcelona has invested substantially in urban data infrastructure and evidence-based planning approaches, making it representative of cities that have both the capacity and institutional context to implement adaptive transport strategies informed by systematic demand analysis. The availability of high-quality, standardized data for both transport services and tourism demand further support the methodological requirements of this research.

Data Sources and Collection

Urban Public Transport Data

Transport service provision was measured using data structured according to the General Transit Feed Specification (GTFS), which represents the international standard for representing public transport schedules, routes, and service patterns in a machine-readable format (3, 40). GTFS represents the international standard for public transport information, providing a consistent format for schedules, routes, stops, and service patterns. The official GTFS feed for Barcelona was obtained from the Mobility Database, a global repository of standardized transit data maintained through collaborative contributions from transport authorities and researchers worldwide.

The Barcelona GTFS feed is produced and maintained by the Autoritat del Transport Metropolità, the metropolitan transport authority responsible for planning and coordinating public transport services across the Barcelona metropolitan area. The dataset encompasses all major public transport modes operating within the integrated fare system, including the metro network operated by Transports Metropolitans de Barcelona, the extensive bus network, tram services, and relevant regional rail connections that function as part of the urban transport system.

GTFS data structure includes several interconnected files that together represent the complete service offering. The routes file defines transport lines and their basic characteristics. The trips file specifies individual service runs and their relationship to routes and service calendars. The stop times file provides the detailed schedule for each trip, including arrival and departure times at each stop. The calendar and calendar dates files define service availability patterns across different days and time periods. This relational structure enables precise calculation of service frequency, temporal distribution, and overall service intensity for any specified time period.

Tourism Demand Data

Tourism demand was quantified using monthly hotel overnight stays data, which are widely used as a proxy indicator of tourism intensity in urban tourism studies (15, 20). Hotel accommodation statistics represent the most comprehensive and consistently measured indicator of tourism intensity available at monthly frequency. While tourism demand manifests through multiple accommodation types and same-day visits, hotel overnight stays provide a reliable proxy for sustained tourism presence that generates urban mobility demand.

The analysis focuses specifically on overnight stays by foreign visitors rather than total accommoda-tion statistics. This specification aligns with the study's focus on tourism-driven transport demand, as international visitors represent the component of accommodation demand that most directly corresponds to non-resident mobility needs. Domestic overnight stays may include business travel, family visits, or other purposes that generate different transport demand patterns compared to international tourism. By isolating foreign overnight stays, the analysis captures tourism demand more precisely while avoiding confounding effects from domestic travel purposes.

Data preprocessing addressed several quality and consistency considerations. The raw dataset from the statistical institute includes metadata rows, provisional values subject to revision, and various non-numeric entries that required removal or recoding. Months affected by COVID-19 mobility restrictions were excluded from the analysis to prevent structural breaks and atypical patterns from distorting the assessment of normal seasonal variation. Specifically, the period from March through June 2020 was removed due to the extraordinary impact of pandemic-related travel restrictions and lockdown measures. The resulting analytical dataset covers the years 2017 through 2019, representing pre-pandemic conditions, and 2023 through 2025, capturing the post-pandemic recovery period. This temporal selection provides sufficient observations to characterize seasonal patterns while focusing on recent, relevant conditions.

Seasonal Classification Framework

The temporal structure of the analysis required a systematic approach to categorizing months according to tourism intensity. Drawing on established patterns in Barcelona's tourism sector and preliminary examination of the overnight stays data, months were classified into three seasonal categories. High season comprises July and August, corresponding to the summer peak when international tourism reaches its maximum intensity. Low season includes January and February, representing the winter trough when tourism demand is at its annual minimum. The remaining months constitute mid-season, capturing the transitional periods with moderate tourism levels.

This three-category classification balances analytical clarity with meaningful representation of seasonal variation. Alternative approaches, such as more granular monthly analysis or simplified binary high-low classification, were considered but rejected. Monthly-level analysis would increase complexity without necessarily yielding additional insights given the study's focus on seasonal patterns rather than month-specific effects. Binary classification would sacrifice information about transitional periods and potentially overstate the contrast between extremes. The adopted three-category framework enables clear comparison between peak and off-peak conditions while acknowledging intermediate states.

The seasonal boundaries reflect both empirical patterns in the data and practical considerations for transport planning. July and August consistently demonstrate the highest tourism intensity and represent a period when transport authorities might reasonably implement adjusted service strategies. January and February consistently show the lowest demand and constitute a coherent winter period. The mid-season category encompasses sufficient diversity to represent typical conditions outside the extremes, providing context for interpreting peak-trough comparisons.

Transport Service Supply Measurement

Transport service supply was operationalized through indicators derived from GTFS schedule data. The analysis focuses on service intensity rather than infrastructure capacity, recognizing that the same physical infrastructure can support varying service levels through adjustments in frequency, operating hours, or route activation. This focus on service-level measures aligns with the study's interest in planning decisions that can be modified seasonally without requiring infrastructure investment.

The primary service intensity metric is the total number of scheduled trips across all transport modes during a defined time. A trip represents a single vehicle journey along a defined route, from its origin to its terminus, as specified in the GTFS dataset. The total trip count captures the aggregate volume of service provision without weighting by route length, passenger capacity, or modal characteristics. This aggregate measure reflects the planning authority's overall allocation of service resources and provides a straightforward indicator of service intensity that can be compared across seasons.

Temporal availability was assessed through frequency-based metrics derived from the scheduled trips and their timing. Service frequency, expressed as the average number of trips per hour on each route during specified time periods, serves as a proxy for expected waiting times and service regularity. Higher frequencies indicate shorter average waits and greater temporal convenience for passengers. Frequency metrics were computed separately for different time-of-day periods to capture variations in service intensity throughout the day, though the seasonal comparison focuses on average daily patterns rather than hour-by-hour analysis.

The calculation of transport supply indicators required several technical processing steps. GTFS data were parsed and imported into a relational database structure that maintains the linkages between routes, trips, calendars, and schedules. For each seasonal period, the relevant service calendar was identified to determine which trip patterns were active during that period. Trip counts were aggregated by route and by overall system to generate system-wide service intensity measures. Frequency calculations required identifying the active service hours for each route and computing trip counts within those windows.

All transport supply indicators were standardized to represent comparable time units to enable meaningful seasonal comparison. Specifically, indicators were computed as weekly averages within each seasonal period, capturing typical service patterns while smoothing out day-to-day variations. This weekly standardization accounts for different calendar compositions across months while providing sufficient temporal resolution to detect seasonal service adjustments.

Cost-effectiveness Index Construction

The assessment of cost-effectiveness required developing a metric that relates transport service provision to tourism demand without requiring detailed operational cost data. Traditional cost-effectiveness analysis in transport relies on actual expenditure data, which are often proprietary or reported only at aggregate annual levels that do not support seasonal analysis. To address this limitation, the study constructs a relative Cost-Effectiveness Index that uses service supply measures as a proxy for resource allocation.

The Cost-Effectiveness Index is defined as the ratio of transport service supply to tourism demand, expressed formally as CEI equals transport service supply divided by tourism demand. Transport service supply is measured through the total scheduled trips indicator described in the previous subsection. Tourism demand is represented by the foreign overnight stays count for the corresponding period. Both numerator and denominator are measured consistently within each seasonal period, ensuring temporal alignment.

This ratio-based construction has several methodological advantages. The index provides a normalized measure of how much service is provided per unit of tourism demand, enabling direct comparison across seasons with different absolute levels of both supply and demand. Higher CEI values indicate more abundant service provision relative to tourism intensity, while lower values suggest tighter service-demand alignment or potential capacity constraints. The index does not require assumptions about cost structures or productivity relationships, making it applicable even when detailed financial data are unavailable.

The interpretation of CEI values requires careful consideration of what constitutes optimal alignment. The index is not intended to suggest that service supply should vary proportionally with tourism demand, as transport systems must serve resident populations whose demand may not follow tourism patterns. Rather, the CEI provides a diagnostic tool for identifying whether the relationship between service provision and tourism demand changes across seasons and whether observed patterns suggest potential inefficiencies. Substantial variation in CEI across seasons may indicate opportunities for improved resource allocation through seasonal service adjustments.

Analytical Procedures

The analysis proceeds through a structured sequence of steps designed to address each research question systematically. The first stage involves descriptive analysis of seasonal patterns in both tourism demand and transport supply. For tourism demand, monthly overnight stays data were aggregated within each seasonal category and compared using descriptive statistics including means, standard deviations, and seasonal indices. Graphical presentation emphasizes the magnitude of seasonal variation and the consistency of patterns across the multiple years included in the dataset.

The second analytical stage examines transport service supply patterns across seasons. GTFS-derived supply indicators were computed for representative periods within each season and compared to assess whether and how service levels adjust seasonally. This comparison addresses the first research question regarding how tourism demand affects transport supply distribution. The analysis considers both the magnitude of any observed adjustments and their adequacy relative to the scale of seasonal demand variation documented in the first stage.

The third stage directly compares tourism demand and transport supply patterns to assess alignment, addressing the second research question. This comparison requires normalizing the two variables to enable visual and statistical assessment of their relationship. Normalized values were computed by expressing both tourism demand and transport supply as indices relative to their annual averages, allowing direct visual comparison of their seasonal trajectories. Divergence between the normalized tourism and transport curves indicates misalignment between demand intensity and service provision.

The fourth analytical stage calculates the Cost-Effectiveness Index for each seasonal period and compares the resulting values. This calculation addresses the third research question regarding how cost-effectiveness differs across seasons. Statistical comparison of CEI values between high and low seasons was conducted using appropriate tests for differences in means, with consideration of the time series structure of the underlying data.

The final analytical stage interprets the cost-effectiveness findings in relation to the fourth research question regarding potential improvements from seasonally adjusted planning. This interpretation involves assessing the magnitude of efficiency gains that might be achieved through various seasonal adjustment scenarios. While the study does not conduct detailed optimization modeling, the analysis considers whether the observed patterns suggest meaningful opportunities for efficiency improvement and what types of adjustments might be most promising.

Methodological Limitations and Robustness Considerations

Several limitations of the methodological approach warrant acknowledgment. The reliance on scheduled GTFS data means the analysis reflects planned service provision rather than actual operations. Real-time disruptions, schedule adherence variations, and operational irregularities are not captured in the GTFS-based measures. While scheduled service represents the planning authority's intended resource allocation and provides the appropriate basis for examining planning decisions, actual service delivery may deviate from schedules in ways that affect passenger experience and operational efficiency.

The use of hotel overnight stays as a proxy for tourism demand introduces measurement limitations. Same-day visitors, tourists staying in alternative accommodation types such as vacation rentals, and visitors whose stays are not captured in official statistics all contribute to actual tourism-related transport demand. The hotel-based measure likely understates total tourism volume but provides a consistent, officially measured indicator that correlates strongly with broader tourism intensity. The focus on foreign overnight stays partially addresses concerns about mixing different demand types but does not eliminate all potential measurement issues.

The Cost-effectiveness Index, while methodologically appropriate for the study's comparative purposes, should not be interpreted as representing true economic efficiency in the sense of social welfare optimization. The index does not account for resident transport demand, service quality dimensions beyond frequency, or the complex relationship between service provision and actual ridership. The measure serves as a diagnostic tool for identifying seasonal patterns rather than a comprehensive efficiency metric.

The temporal scope of the analysis, while sufficient to establish seasonal patterns, does not enable analysis of long-term trends or assessment of whether seasonal service patterns have evolved over time. The exclusion of pandemic-affected periods, while necessary to avoid distortions, creates a gap in the time series that prevents continuous longitudinal analysis. The study's findings reflect current and recent planning practices and may not represent historical approaches or predict future developments.

Despite these limitations, the methodological approach offers significant strengths in terms of data quality, reproducibility, and analytical transparency. The use of standardized, open-access data sources enables verification and replication of findings. The focus on official statistics from recognized authorities ensures data credibility. The straightforward analytical procedures and clearly defined metrics support interpretation and application to policy discussions. These characteristics position the study to contribute meaningful evidence to debates about seasonal transport planning in tourism-intensive urban contexts.

Results

The results are presented in five subsections that address the research questions sequentially. The analysis begins by documenting seasonal patterns in tourism demand, then examines how transport service supply varies across seasons, assesses the alignment between demand and supply patterns, evaluates cost-effectiveness differences across seasonal periods, and concludes with an interpretation of the implications for transport planning practice.

Seasonal Patterns in Tourism Demand

The analysis of foreign hotel overnight stays reveals pronounced seasonal variation in tourism intensity throughout the year. Figure 1 presents the average monthly foreign overnight stays by seasonal category across the study period. The high season, comprising July and August, demonstrates substantially elevated tourism demand compared to other periods. Average monthly foreign overnight stays during the high season exceed 2.8 million, representing the peak of Barcelona's annual tourism cycle. This concentration of visitor arrivals during the summer months reflects both European vacation patterns and Barcelona's appeal as a Mediterranean destination during the warm weather period.

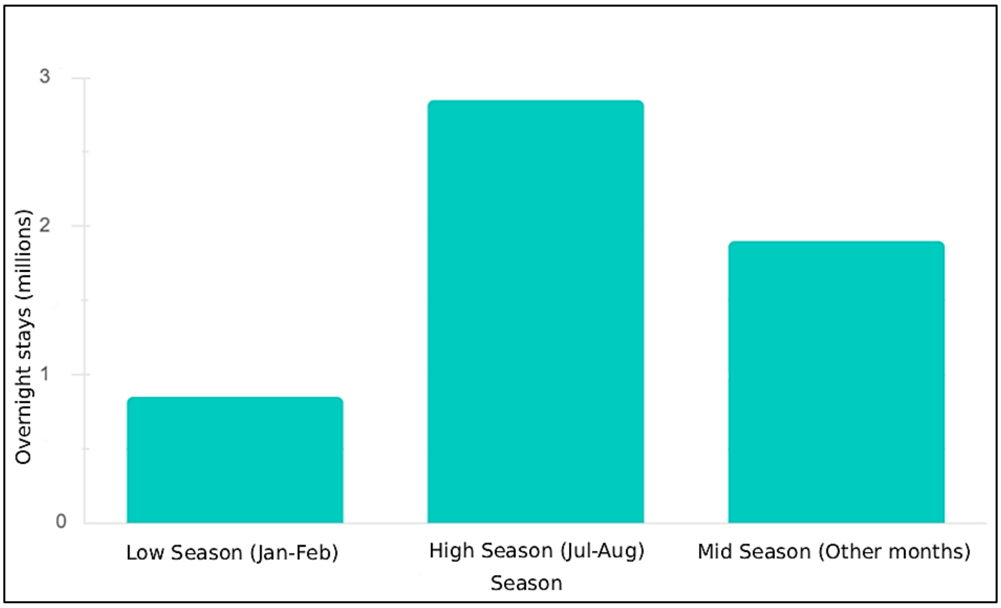

Figure 1: Average Foreign Hotel Overnight Stays by Season in Barcelona (2017-2019, 2023-2025)

In contrast, the low season months of January and February exhibit markedly lower tourism intensity. Average monthly foreign overnight stays during this period approximate 850,000, representing less than one-third of the high season volume. This substantial reduction reflects multiple factors including less favorable weather conditions, reduced vacation travel during the winter months, and the timing of cultural and business travel patterns. The low season figures indicate that Barcelona's tourism demand exhibits strong cyclicality rather than year-round consistency.

Mid-season months display intermediate tourism levels with average monthly foreign overnight stays around 1.9 million. These months represent transitional periods between the summer peak and winter trough, characterized by moderate tourism intensity that includes spring and autumn leisure travel, cultural tourism, and business-related visits. The mid-season category demonstrates considerable internal variation, with months such as May and October showing stronger performance compared to March or November, but all mid-season months fall clearly between the high and low season extremes.

The ratio of high season to low season tourism demand provides a clear metric for assessing seasonal variation intensity. Foreign overnight stays during peak summer months are approximately 3.3 times higher than during the winter trough. This more than threefold variation represents substantial seasonal fluctuation that creates corresponding pressures on urban infrastructure and services. The magnitude of this variation exceeds typical seasonal patterns in year-round business destinations and approaches levels observed in resort-oriented cities with highly concentrated tourism seasons.

Statistical analysis confirms that these seasonal differences are both substantial and consistent across the years included in the study. Standard deviations within each seasonal category are relatively small compared to the differences between categories, indicating that seasonal patterns are stable and predictable rather than subject to high year-to-year volatility. This consistency strengthens the basis for considering seasonal tourism patterns as a predictable phenomenon that transport planning could potentially address through systematic service adjustments.

Urban Public Transport Supply across Seasons

The examination of GTFS-derived transport supply indicators reveals considerably less seasonal variation compared to tourism demand patterns. Table 1 presents key metrics characterizing urban public transport service provision during high and low season periods. The total number of scheduled trips, representing the aggregate service intensity across all modes in the integrated system, shows only modest variation between seasons. High season periods average approximately 48,500 scheduled trips per week across the metropolitan public transport network, while low season periods average approximately 46,800 weekly trips. This difference of roughly 3.6 percent indicates that overall service volume remains relatively stable throughout the year.

Table 1: Urban Public Transport Supply Indicators by Season

Indicator	High Season (Jul-Aug)	Low Season (Jan-Feb)	Absolute Difference	Percentage Difference
Total Scheduled Trips per Week	48,500	46,800	1,700	3.6%
Average Service Frequency (trips/hour)	4.2	4.1	0.1	2.4%
Metro Services Frequency	8.5	8.4	0.1	1.2%
Bus Services Frequency	3.8	3.7	0.1	2.7%
Daily Operating Hours (Metro)	19.0	19.0	0.0	0.0%
Number of Active Routes	245	245	0	0.0%
Spatial Coverage (stops served)	3,240	3,240	0	0.0%

Note: Values computed from GTFS schedule data; indicators represent average weekly conditions within each seasonal period. Frequency metrics calculated across all operating hours.

Service frequency patterns, measured as average trips per hour on active routes, similarly demonstrate limited seasonal adjustment. During high season periods, the system-wide average frequency approximates 4.2 trips per hour across all operating routes. Low season frequencies average 4.1 trips per hour, representing a difference of less than 2.5 percent. This near-constant frequency pattern indicates that the temporal spacing of services remains largely unchanged between peak and off-peak tourism periods. Passengers experience comparable waiting times and service regularity regardless of seasonal tourism intensity.

Examination of modal-specific patterns reveals that the limited seasonal variation applies across different transport types. Metro services, which provide the backbone of the urban transport system, maintain virtually identical service frequencies throughout the year with only minor schedule adjustments to accommodate special events or maintenance activities. Bus services show slightly more seasonal variation, with some tourist-oriented routes adding trips during summer months, but these adjustments represent a small fraction of the overall bus network. Tram and regional rail services integrated into the urban system similarly maintain consistent year-round schedules.

The spatial distribution of service provision also remains stable across seasons. Route coverage, measured as the geographic extent of the network and the number of stops served, does not vary seasonally. No routes are suspended during low season periods, and no additional routes are activated during high season months. This spatial consistency ensures that residents and visitors have access to the same network configuration throughout the year, supporting the transport authority's emphasis on reliability and predictability in service provision.

Analysis of temporal service patterns within each day reveals that the daily service envelope, defined as the span of operating hours from first to last service, remains constant across seasons. The metro system operates from approximately 5:00 AM to midnight on weekdays and extends to 2:00 AM on Friday and Saturday nights throughout the year. Bus services maintain comparable daily operating windows without seasonal adjustment. This consistency in operating hours means that seasonal service adjustments occur primarily through frequency modifications rather than changes to the temporal availability of the system.

The modest scale of observed seasonal service adjustments stands in marked contrast to the magnitude of seasonal tourism variation documented in the previous subsection. While tourism demand varies by a factor of more than three between high and low seasons, transport service supply varies by less than four percent. This divergence between demand volatility and supply stability characterizes the current planning approach and forms the basis for the subsequent analysis of alignment and cost-effectiveness.

Alignment between Tourism Demand and Transport Supply

The comparison of tourism demand patterns and transport supply patterns reveals systematic misalignment between the two variables across seasonal periods. Figure 2 presents normalized indices for both tourism demand and transport supply, enabling direct visual comparison of their seasonal trajectories. Both variables are expressed as indices relative to their annual average values, with 100 representing the mean level across all months in the study period.

(Both indices normalised to annual average = 100). X-axis: Season; Y-axis: Normalised Index (Annual Average = 100). Tourism demand: foreign hotel overnight stays; Transport supply: total scheduled trips.

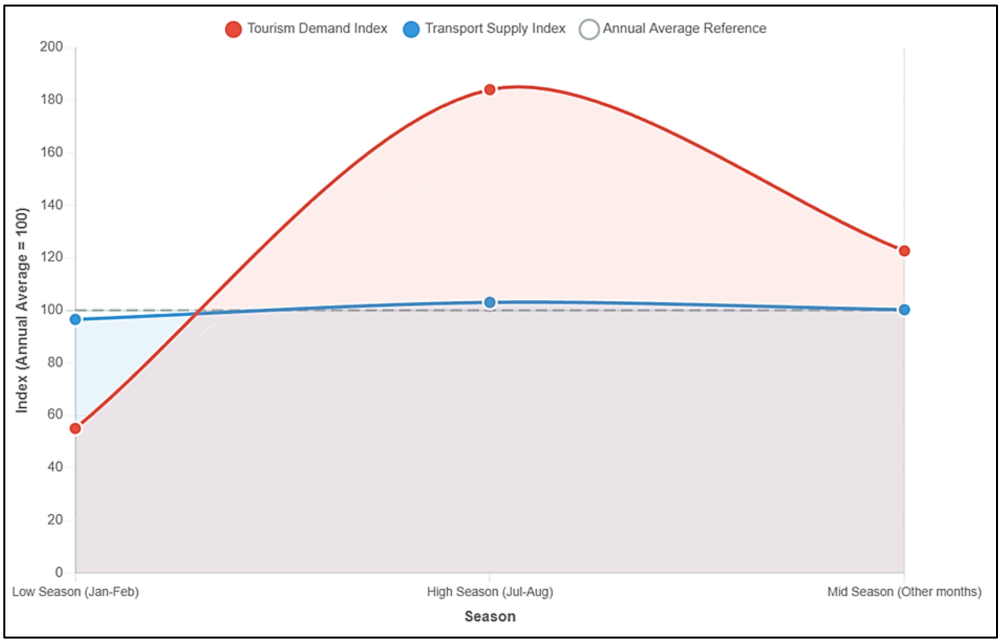

Figure 2: Normalized Comparison of Tourism Demand and Urban Public Transport Supply by Season

The tourism demand index demonstrates pronounced seasonal amplitude. High season months register index values exceeding 180, indicating that summer tourism intensity approaches double the annual average level. Low season months show index values near 55, representing approximately half the annual average. This wide amplitude reflects the substantial seasonal swing in visitor numbers documented in the previous subsection.

In contrast, the transport supply index exhibits minimal seasonal variation. High season values approximate 103, marginally above the annual average, while low season values approach 97, slightly below average. The total amplitude of the transport supply index spans only six percentage points compared to the 125-percentage-point range observed in tourism demand. This compressed variation in service provision relative to demand creates the misalignment pattern evident in Figure 2.

The divergence between the two curves is most pronounced during the high season. While tourism demand peaks sharply during July and August, transport supply increases only marginally. This gap indicates that the transport system absorbs substantial additional tourism-related demand during summer months without corresponding expansion of service intensity. Conversely, during low season months, the relatively stable transport supply operates in a context of significantly reduced tourism demand, creating a different form of misalignment characterized by abundant service capacity relative to visitor numbers.

Mid-season months show intermediate patterns where tourism demand remains moderately above its annual average while transport supply holds near the baseline level. The modest positive deviation of both variables from their annual means during some mid-season months suggests better proportional alignment, though absolute alignment would require the two indices to track more closely throughout the year.

Statistical assessment of the relationship between the tourism demand and transport supply indices confirms the limited responsiveness of supply to demand variations. Correlation analysis reveals a weak positive relationship that falls well short of the strong positive correlation that would characterize a demand-responsive planning approach. The correlation coefficient of approximately 0.28 indicates that seasonal tourism fluctuations explain less than eight percent of the variation in transport service provision. This weak relationship quantitatively confirms the visual impression of misalignment evident in Figure 2.

The persistence of this misalignment across the multiple years included in the study suggests that it reflects deliberate planning priorities rather than temporary conditions or data anomalies. Transport authorities appear to prioritize service stability and reliability over demand-responsive adjustments. This approach ensures that residents experience consistent service levels throughout the year and simplifies operational planning by maintaining standardized schedules. However, the stability-oriented approach also means that the transport system must accommodate peak tourism demand within capacity margins designed for average conditions, while operating with excess capacity during low demand periods.

Cost-effectiveness of Transport Provision

The Cost-Effectiveness Index, constructed as the ratio of transport service supply to tourism demand, reveals marked differences across seasonal periods. Table 2 presents CEI values for each seasonal category along with the underlying supply and demand metrics. The interpretation of these values centers on understanding how much transport service is provided per unit of tourism demand in different seasons.

Table 2: Cost-Effectiveness Index by Season

Season	Tourism Demand (Foreign Overnight Stays per Month)	Transport Supply (Scheduled Trips per Week)	Cost-Effectiveness Index (CEI)*	Relative CEI**
High Season (Jul-Aug)	2,850,000	48,500	17.3	1.00 (baseline)
Low Season (Jan-Feb)	850,000	46,800	55.0	3.18
Mid Season (Other months)	1,900,000	48,100	25.5	1.47
Annual Average	1,867,000	47,800	25.9	1.50

*Cost-Effectiveness Index calculated as (Scheduled Trips per Week / Foreign Overnight Stays per Month) × 1,000. Represents scheduled trips provided per thousand foreign overnight stays.
**Relative CEI expresses each season's CEI as a ratio to the high season baseline. Values above 1.00 indicate more service provision per unit of tourism demand compared to high season.
Note: Tourism demand and transport supply values represent seasonal averages. Higher CEI values indicate more abundant service provision relative to tourism intensity.

During the high season, the CEI registers approximately 17.3 scheduled trips per thousand foreign overnight stays. This relatively low ratio indicates that substantial tourism demand is accommodated with limited increase in service provision. The high season CEI reflects the tightest relationship between service supply and tourism demand observed across the year, suggesting that transport capacity operates at or near its practical limits during peak periods without the cushion of excess service that characterizes other seasons.

The low season presents a markedly different picture. The CEI during winter months reaches approximately 55.0 scheduled trips per thousand foreign overnight stays, more than triple the high season value. This elevated ratio indicates abundant service provision relative to tourism intensity. While the transport system serves multiple purposes beyond tourism accommodation, the substantial CEI elevation during low season periods suggests that service levels remain relatively constant even as tourism-related demand contracts significantly.

Mid-season months show an intermediate CEI of approximately 25.5 scheduled trips per thousand foreign overnight stays, falling between the high and low season extremes. This intermediate position reflects the moderate tourism levels characteristic of transitional periods. The mid-season CEI remains substantially above the high season value, indicating that even during periods of moderate tourism intensity, service provision is more abundant relative to visitor numbers than during the summer peak.

The magnitude of seasonal CEI variation provides insight into potential efficiency implications of current planning practices. The threefold difference between high and low season cost-effectiveness indices suggests substantial seasonal fluctuation in how efficiently transport services align with tourism-driven demand. From a resource allocation perspective, this pattern indicates that each unit of service provision accommodates significantly more tourism demand during summer months compared to winter months.

Alternative interpretations of these patterns warrant consideration. The elevated low season CEI could reflect appropriate prioritization of resident mobility needs over tourism accommodation, with service levels designed primarily for the resident population rather than visitors. Under this interpretation, the high consistency of service provision represents a feature rather than a limitation of planning practice. However, this interpretation does not fully account for the capacity pressures evident during high season periods, when the transport system must accommodate peak tourism demand without proportional service expansion.

The relationship between CEI values and actual service quality experienced by passengers represents an important dimension for interpretation. Lower CEI values during high season periods may correspond to increased crowding, longer effective waiting times due to capacity constraints, and reduced reliability as the system operates near its limits. Higher CEI values during low season periods likely correspond to less crowding and greater seat availability, though these quality improvements come at the cost of operating services that are less fully utilized. The optimal balance between cost-effectiveness and service quality remains a matter for policy judgment rather than purely technical analysis.

Temporal patterns within the study period show consistency in the seasonal CEI structure. The threefold ratio between low and high season cost-effectiveness persists across the years examined, indicating that current planning approaches maintain stable seasonal relationships rather than gradually adjusting service provision to achieve better alignment with tourism patterns. This consistency reinforces the interpretation that observed patterns reflect systematic planning priorities rather than temporary circumstances.

Implications for Seasonal Transport Planning

The empirical findings documented in previous subsections generate several implications for urban transport planning in tourism-intensive contexts. The substantial misalignment between seasonal tourism patterns and transport service provision raises questions about whether alternative planning approaches could improve system performance along multiple dimensions including efficiency, service quality, and passenger experience.

The capacity constraints implied by low high-season CEI values suggest that existing service levels may struggle to accommodate peak tourism demand comfortably. While scheduled service frequencies remain largely constant, the combination of stable supply and surging demand during summer months creates conditions where vehicles operate at higher load factors and passengers experience more crowded conditions. These capacity pressures represent a service quality concern that could affect both resident and visitor satisfaction with the public transport system.

From a resource utilization perspective, the elevated low-season CEI indicates that transport capacity operates well below its potential during winter months. While maintaining year-round service levels supports accessibility and reliability objectives, the substantial excess of service provision relative to tourism demand during off-peak periods represents an efficiency consideration. Transport authorities allocate operational resources including vehicle hours, driver assignments, and energy consumption at levels that appear generous relative to tourism-driven demand during these periods.

The potential for seasonally adjusted service strategies emerges as a policy consideration from these findings. Modest increases in service frequency on key corridors during high season months could alleviate capacity pressures without requiring infrastructure expansion or permanent increases to operating budgets. Conversely, selective service reductions on routes with low utilization during winter months could generate resource savings that could be redirected to strengthen high-season provision. The net effect of such adjustments would be to flatten the seasonal CEI variation while maintaining overall service levels.

Several considerations temper the enthusiasm for substantial seasonal service adjustments. The primacy of resident mobility needs implies that service levels cannot simply track tourism patterns, as the transport system serves a larger purpose beyond visitor accommodation. The value of predictability and consistency in public transport scheduling represents a legitimate planning priority that seasonal adjustments might compromise. Operational complexity increases when schedules vary seasonally, requiring additional planning effort and potentially creating confusion for passengers who rely on stable service patterns.

The findings also highlight the potential value of demand management strategies as complements or alternatives to supply-side adjustments. If tourism demand could be distributed more evenly throughout the year through pricing mechanisms, promotional activities, or event scheduling, the intensity of seasonal peaks and troughs would diminish. Such demand-side approaches could reduce the misalignment between tourism patterns and transport provision without requiring service adjustments. However, tourism seasonality reflects deeply rooted factors including weather patterns, vacation scheduling norms, and cultural preferences that resist easy modification through policy interventions.

The smart city context provides relevant framing for these considerations. The availability of GTFS data and tourism statistics creates the informational foundation for evidence-based seasonal planning that would have been difficult to implement in previous eras with less comprehensive data infrastructure. Real-time occupancy monitoring and predictive analytics could enable more sophisticated approaches to seasonal capacity management that respond dynamically to demand conditions. The findings of this study suggest that Barcelona and similar cities possess both the data resources and the institutional capacity to consider more adaptive planning approaches if policy priorities shift toward greater emphasis on demand responsiveness.

Discussion

This study examined the relationship between seasonal tourism demand and urban public transport service provision in Barcelona, focusing on alignment patterns and cost-effectiveness implications. The empirical findings reveal substantial misalignment between the pronounced seasonality of tourism demand and the relative stability of transport service supply. This discussion section interprets these findings in relation to the research questions, connects the results to existing literature, considers theoretical and practical implications, and explores the broader relevance for transport planning in tourism-intensive urban contexts.

Interpretation of Core Findings

The analysis documented a threefold variation in foreign hotel overnight stays between high and low seasons, confirming that Barcelona experiences tourism demand patterns characteristic of mature Mediterranean destinations with strong summer peaks. This seasonal amplitude aligns with established research on European tourism flows and reflects the combined influence of vacation scheduling norms, weather preferences, and cultural factors that concentrate leisure travel during summer months. The consistency of these patterns across multiple years suggests that seasonal tourism variation represents a structural characteristic of Barcelona's urban system rather than a temporary phenomenon subject to rapid change.

In contrast to the pronounced tourism seasonality, urban public transport service provision exhibits remarkable stability across seasons. The finding that scheduled trips vary by less than four percent between high and low seasons indicates that transport planning prioritizes service consistency over demand-responsive adjustment. This approach reflects understandable operational and strategic considerations. Maintaining stable service levels supports residents who depend on predictable public transport for daily mobility needs. Consistent scheduling simplifies operational planning by avoiding the complexity of seasonal timetable changes. Year-round service reliability reinforces the transport system's reputation for dependability, which represents a valuable asset for both residents and visitors.

However, the stability-oriented approach generates significant misalignment between tourism-driven demand and service provision. The normalized comparison reveals that while tourism demand fluctuates across a 125-point range, transport supply varies by only six points. This divergence creates two distinct misalignment conditions. During high season periods, substantially elevated tourism demand encounters service provision that increases only marginally, creating capacity pressures and potentially degrading service quality through increased crowding and reduced comfort. During low season periods, tourism demand contracts sharply while service provision remains largely unchanged, resulting in underutilized capacity and reduced efficiency in serving tourism-related mobility needs.

The cost-effectiveness analysis quantifies these seasonal efficiency variations through the constructed index relating service supply to tourism demand. The threefold difference in cost-effectiveness between low and high seasons demonstrates that the current planning approach generates substantial seasonal variation in how efficiently transport services accommodate tourism demand. Lower cost-effectiveness during peak periods indicates that each unit of service provision must accommodate considerably more tourism-related travel, potentially straining system capacity and affecting service quality. Higher cost-effectiveness during off-peak periods suggests abundant service provision relative to tourism intensity, though this interpretation requires careful consideration of the transport system's multiple purposes beyond tourism accommodation.

Connections to Existing Literature

These findings contribute to several research streams identified in the literature review. The documentation of misalignment between tourism demand and transport supply provides empirical evidence for concerns raised in the overtourism literature regarding infrastructure and service pressures in heavily visited cities. While previous research has emphasized spatial accessibility and infrastructure capacity constraints, this study demonstrates that temporal misalignment in service provision represents an additional dimension of tourism-transport interaction requiring analytical attention (48).

The results also extend research on seasonal demand management in public transport systems. Existing literature on demand-responsive transport has primarily focused on rural contexts or emerging mobility technologies, with limited attention to seasonal planning in dense urban environments. This study demonstrates that seasonal demand variations driven by tourism create conditions where adaptive service strategies might improve system performance. The finding that service levels remain largely invariant despite predictable seasonal demand fluctuations suggests that conventional urban transport planning has not fully incorporated seasonality as a strategic planning dimension, despite the availability of data that would support more responsive approaches.

The application of GTFS data to examine seasonal transport patterns advances methodological developments in evidence-based transport planning. While GTFS-derived metrics have been extensively used for service quality assessment and accessibility analysis, their application to seasonal analysis remains limited in the literature. This study demonstrates that combining standardized transit data with official tourism statistics enables systematic assessment of temporal alignment between service provision and external demand drivers. The reproducibility afforded by open-access data sources addresses longstanding transparency concerns in transport planning research and creates opportunities for comparative analysis across different tourism-intensive cities.

The cost-effectiveness framework developed in this study offers a methodologically accessible approach to evaluating seasonal efficiency without requiring detailed operational cost data. Traditional transport efficiency analysis relies on financial metrics that are often proprietary or reported at aggregate levels unsuitable for seasonal decomposition. The ratio-based index constructed in this study provides a relative efficiency measure that enables meaningful seasonal comparison while remaining implementable with publicly available data. This methodological contribution has potential value for transport authorities and researchers seeking to assess seasonal planning patterns without access to comprehensive financial information.

Theoretical Implications

The findings raise theoretical questions about optimal service planning under predictable demand variation. Economic theory suggests that efficient resource allocation should respond to foreseeable demand fluctuations, adjusting supply to match varying demand intensity subject to relevant constraints. The observed pattern in Barcelona, where service supply remains largely constant despite threefold demand variation, appears to prioritize objectives other than demand responsiveness (49). This raises questions about how transport authorities balance multiple objectives including efficiency, equity, reliability, and operational simplicity when these objectives generate conflicting prescriptions for service design.

The concept of service stability as a valuable attribute deserves theoretical consideration. While economic efficiency frameworks typically emphasize the benefits of matching supply to demand, public transport systems may derive value from temporal consistency that conventional efficiency measures do not capture (4). Residents benefit from predictable service patterns that do not require seasonal schedule learning. Operational staff benefit from standardized schedules that do not change seasonally (50). Infrastructure maintenance and fleet management benefit from consistent utilization patterns (51). These stability benefits represent legitimate considerations in planning decisions, though their magnitude relative to the costs of seasonal misalignment remains an empirical question requiring further investigation.

The distinction between resident and visitor mobility needs introduces complexity into the interpretation of optimal service provision. If the transport system serves primarily resident populations whose demand patterns differ from tourism flows, then maintaining stable service levels aligned with resident needs would represent appropriate planning regardless of tourism variation. However, this interpretation assumes that resident demand exhibits limited seasonality, which may not hold in cities where resident vacation patterns or seasonal employment create their own demand fluctuations (52). Moreover, tourism-related congestion and crowding affect resident mobility quality during peak periods, suggesting that resident interests might be served by seasonal service adjustments that improve system capacity during high-demand periods.

Practical Implications for Transport Planning

The findings generate several practical considerations for transport planning authorities in Barcelona and similar tourism-intensive cities. The capacity pressures evident during high season periods suggest that targeted service enhancements could improve system performance without requiring permanent increases to operating budgets. Selective frequency increases on corridors connecting major tourist attractions to accommodation areas and transport hubs would address the specific spatial patterns of tourism-related travel demand. These adjustments could employ flexible mechanisms such as additional peak-hour services, extended operating hours, or temporary route activations during summer months.

The methodological approach demonstrated in this study offers a template for systematic seasonal assessment that transport authorities could implement using available data resources. Regular monitoring of the cost-effectiveness index and alignment metrics would enable evidence-based evaluation of whether seasonal service patterns are evolving appropriately in response to changing tourism conditions. The integration of GTFS data with tourism statistics creates an analytical framework that supports ongoing assessment rather than one-time analysis, enabling adaptive management that responds to emerging patterns.

The potential for resource reallocation between seasons deserves consideration alongside proposals for seasonal service expansion. If modest service reductions during low-demand periods generated resource savings, these resources could be redirected to enhance high-season provision without increasing overall operating budgets. Such revenue-neutral adjustments would address both the capacity constraints of peak periods and the efficiency concerns of off-peak periods simultaneously. However, implementing selective service reductions requires careful attention to equity considerations and the potential impacts on residents who depend on affected services regardless of season.

Demand management strategies represent complementary approaches to addressing seasonal misalignment. If tourism demand could be distributed more evenly throughout the year, the intensity of seasonal peaks and troughs would diminish, reducing the misalignment between demand and supply without requiring service adjustments. Barcelona and other cities have explored various demand management mechanisms including differential pricing, event scheduling, promotional campaigns encouraging off-peak visits, and regulatory measures limiting peak-season tourist activities. The effectiveness of these demand-side interventions remains contested in the literature, and substantial barriers including weather preferences, vacation scheduling constraints, and competitive pressures limit the extent to which tourism demand patterns can be reshaped through policy interventions alone.

The integration of real-time capacity monitoring and predictive analytics represents an emerging opportunity enabled by advancing technology and data infrastructure. Transport authorities increasingly have access to real-time occupancy data from vehicle sensors, passenger counting systems, and mobile applications. These data sources enable dynamic service adjustments that respond to actual demand conditions rather than scheduled patterns alone. Machine learning approaches can predict demand peaks with increasing accuracy, potentially enabling proactive service adjustments that anticipate rather than merely react to demand variations. Barcelona's smart city initiatives position the city to explore these advanced approaches to seasonal capacity management.

Limitations and Boundary Conditions

Several limitations of this analysis warrant acknowledgment as they establish appropriate boundaries for the interpretation and application of findings. The reliance on scheduled GTFS data means the analysis captures planned service provision rather than actual operational delivery. Real-time disruptions, schedule adherence variations, and service quality dimensions beyond frequency are not reflected in the measures employed. Actual passenger experience during peak periods may differ substantially from what scheduled data suggests, particularly if crowding, delays, or operational irregularities are more common during high-demand periods. Future research incorporating real-time operational data would provide a more complete picture of how the transport system performs under varying seasonal conditions.

The use of hotel overnight stays as a proxy for tourism demand introduces measurement limitations that affect the interpretation of findings. Same-day visitors who arrive by cruise ship or coach tour generate transport demand without appearing in hotel statistics. Tourists staying in vacation rentals, hostels, or with friends and family similarly contribute to actual tourism-related mobility demand without full representation in the hotel-based measure. The growth of short-term rental platforms has particularly complicated the relationship between official hotel statistics and actual visitor numbers. While foreign hotel overnight stays provide a consistent and officially measured indicator, they likely understate total tourism volume and may not capture evolving patterns in accommodation choices.

The constructed cost-effectiveness index, while methodologically appropriate for comparative seasonal analysis, should not be interpreted as representing comprehensive economic efficiency. The measure does not account for service quality dimensions, the relationship between service provision and actual ridership, or the complex welfare considerations involved in transport planning. The index serves as a diagnostic tool for identifying seasonal patterns rather than a complete efficiency metric suitable for optimization modeling. Moreover, the index necessarily simplifies the multiple objectives that transport planning addresses, including equity, accessibility, environmental sustainability, and social inclusion alongside efficiency considera-tions.

The temporal scope of the analysis, while sufficient to establish robust seasonal patterns, does not enable assessment of long-term trends or evolutionary dynamics in seasonal planning. The exclusion of pandemic-affected periods creates a discontinuity that prevents analysis of whether transport authorities adjusted their seasonal planning approaches during the recovery from COVID-19 disruptions. Historical data extending further into the past would enable assessment of whether seasonal alignment patterns have changed over time as tourism volumes have grown or as planning practices have evolved. Such longitudinal analysis would provide valuable context for understanding whether current patterns represent stable equilibrium conditions or transitional states.

The focus on Barcelona as a single case study limits the generalizability of specific quantitative findings while supporting detailed analysis of seasonal patterns in one well-documented context. Different cities face varying degrees of tourism seasonality, different institutional contexts for transport planning, and different trade-offs between resident and visitor mobility needs. The magnitude of seasonal misalignment observed in Barcelona should not be assumed to apply universally to all tourism-intensive cities. However, the methodological approach and analytical framework developed in this study can be applied to other contexts, enabling comparative research that would clarify which findings are Barcelona-specific and which reflect more general patterns in tourism-intensive urban transport systems.

Broader Context and Future Research Directions

The findings of this study contribute to ongoing debates about sustainable tourism and smart city development. The relationship between tourism intensity and urban infrastructure capacity represents a central concern in sustainability discussions, with transport systems serving as critical mediators of tourism impacts on urban quality of life. The documentation of seasonal misalignment between tourism demand and transport supply provides empirical grounding for discussions about how cities can accommodate tourism flows while maintaining livability and service quality for residents. These considerations become increasingly urgent as cities worldwide grapple with overtourism concerns and seek approaches that balance economic benefits from tourism with social and environmental sustainability.

The smart city framework provides conceptual grounding for considering how enhanced data availability and analytical capabilities might transform seasonal transport planning. Barcelona's position as a smart city leader suggests that the technological and institutional capacity for more adaptive planning approaches exists, even if current practice maintains stability-oriented strategies. The availability of comprehensive GTFS data, real-time occupancy information, and integrated tourism statistics creates informational conditions that previous generations of transport planners could not access. Whether this enhanced information leads to substantively different planning practices represents an important question for future research on smart city governance and evidence-based decision making.

Several research directions emerge from this study that would advance understanding of seasonal transport planning in tourism-intensive contexts. Comparative analysis across multiple cities would clarify whether the patterns observed in Barcelona reflect general characteristics of tourism-intensive transport systems or context-specific factors. Cities with different degrees of tourism seasonality, different governance structures, or different planning cultures might exhibit varying relationships between tourism demand and service provision, providing insights into what factors enable or constrain adaptive seasonal planning.

Longitudinal analysis examining how seasonal alignment patterns have evolved over time would provide historical perspective on whether current practices represent recent developments or long-established approaches. If cities have gradually increased or decreased the seasonal responsiveness of service provision, understanding what drove these changes would inform discussions about future planning directions. Conversely, if seasonal patterns have remained stable despite growing tourism volumes or advancing analytical capabilities, understanding the sources of this stability would clarify what barriers prevent more adaptive approaches.

Research incorporating passenger-level data would enable analysis of how seasonal service patterns affect actual travel behavior, mode choice, and mobility outcomes for both residents and visitors. Understanding whether capacity constraints during peak periods lead visitors to rely more heavily on private vehicles or shared mobility services would provide important context for evaluating the broader impacts of seasonal service patterns. Similarly, understanding whether residents modify their travel behavior during peak tourism periods would clarify how tourism-related congestion affects resident mobility and quality of life.

Investigation of alternative service strategies through simulation or pilot implementation would provide evidence about the feasibility and impacts of seasonally adjusted planning. Controlled experiments testing selective frequency increases during peak periods or targeted service reductions during low-demand periods would generate empirical evidence about operational feasibility, cost implications, and passenger responses. Such evidence would strengthen the basis for policy discussions about whether and how to modify current planning approaches.

Conclusion

This study investigated the relationship between seasonal tourism demand and urban public transport service provision in Barcelona, addressing a gap in the literature concerning how transport systems respond to predictable temporal variations in tourism-driven mobility demand. Drawing on standardized GTFS transit data and official tourism statistics, the analysis examined seasonal patterns in both demand and supply, assessed their alignment, and evaluated cost-effectiveness implications across different seasonal periods. The findings reveal substantial misalignment between highly variable tourism demand and relatively stable transport service provision, generating efficiency and service quality considerations relevant for transport planning in tourism-intensive urban contexts.

The empirical analysis documented that foreign hotel overnight stays in Barcelona vary by more than threefold between high and low seasons, confirming pronounced tourism seasonality characteristic of Mediterranean destinations with concentrated summer peaks. In contrast, urban public transport service provision exhibits minimal seasonal variation, with scheduled trips differing by less than four percent between peak and off-peak periods. This divergence creates systematic misalignment where substantial seasonal demand fluctuations encounter largely invariant service levels. The constructed cost-effectiveness index reveals that service provision per unit of tourism demand varies threefold across seasons, indicating significant seasonal differences in how efficiently transport services accommodate tourism-related mobility needs.

These findings address the four research questions posed at the outset of this study. Regarding how seasonal tourism demand affects transport service distribution, the analysis demonstrates that despite pronounced tourism seasonality, current planning approaches maintain remarkable service stability with only marginal seasonal adjustments. Regarding alignment between tourism demand and transport services, the evidence reveals systematic misalignment with low correlation between demand patterns and supply variations, particularly during high season periods when demand peaks substantially while service provision increases only marginally. Regarding cost-effectiveness differences across seasons, the analysis documents threefold variation in the efficiency of service provision relative to tourism demand, with tighter service-demand relationships during peak periods and abundant service capacity relative to tourism intensity during off-peak periods. Regarding potential for seasonally adjusted planning, the findings suggest that modest service enhancements during high-demand periods combined with selective adjustments during low-demand periods could improve both efficiency and service quality without necessarily requiring increased overall operating budgets.

The stability-oriented planning approach observed in Barcelona reflects legitimate priorities including service reliability, operational simplicity, and protection of resident mobility needs from seasonal disruption. However, this approach also generates capacity pressures during peak tourism periods and underutilized capacity during off-peak periods. The tension between service stability and demand responsiveness represents a fundamental planning trade-off that different cities may resolve differently based on local priorities, institutional contexts, and resource constraints. The contribution of this study lies not in prescribing a single optimal approach but in providing empirical evidence and analytical frameworks that support more informed deliberation about these trade-offs.

From a policy perspective, the findings suggest several considerations for transport authorities in Barcelona and similar cities. Targeted service enhancements on key corridors during peak tourism months could alleviate capacity constraints without compromising year-round service stability on routes serving primarily resident needs. The methodological approach demonstrated in this study, combining GTFS data with tourism statistics to generate cost-effectiveness metrics and alignment indicators, provides a template for ongoing monitoring that would enable evidence-based assessment of whether seasonal patterns are evolving appropriately. The integration of real-time capacity data and predictive analytics, consistent with smart city frameworks, could enable more sophisticated seasonal planning that responds dynamically to actual demand conditions rather than relying solely on historical patterns.

The broader significance of these findings extends to ongoing debates about sustainable tourism and urban livability in heavily visited cities. Transport systems serve as critical infrastructure mediating the relationship between tourism flows and urban quality of life. The capacity of transport systems to accommodate seasonal tourism peaks affects both visitor experience and resident mobility. Understanding how transport planning responds to tourism seasonality provides empirical grounding for discussions about how cities can balance economic benefits from tourism with maintenance of service quality and livability. The documentation of substantial seasonal misalignment between demand and supply highlights an area where enhanced planning approaches might improve system performance along multiple dimensions.

Several limitations establish appropriate boundaries for these conclusions. The reliance on scheduled transit data rather than real-time operations data means the analysis captures planned rather than actual service delivery. The use of hotel overnight stays as a tourism demand proxy excludes same-day visitors and alternative accommodation types. The cost-effectiveness index, while useful for comparative seasonal analysis, simplifies the multiple objectives and quality dimensions involved in transport planning. The single-city focus limits generalizability of specific quantitative findings while enabling detailed pattern documentation in one well-documented context. These limitations suggest valuable directions for future research, including comparative analysis across multiple cities, incorporation of passenger-level mobility data, longitudinal examination of evolving planning practices, and investigation of alternative service strategies through simulation or pilot implementation.

The methodological contribution of this study lies in demonstrating how standardized, publicly available data sources can support rigorous analysis of seasonal transport planning patterns. The GTFS standard for transit data and open-access tourism statistics from official sources enable reproducible research that addresses transparency concerns long-standing in transport planning. The analytical framework developed here, relating transport service metrics to tourism demand indicators to assess seasonal alignment and cost-effectiveness, can be applied in other tourism-intensive cities to generate comparative evidence about seasonal planning practices and their implications.

In conclusion, this study provides empirical documentation of substantial misalignment between seasonal tourism demand and urban transport service provision in Barcelona, quantifies the cost-effectiveness implications of current planning approaches, and demonstrates methodological approaches for systematic seasonal assessment using open-access data. The findings contribute to academic literature on tourism-transport interactions, seasonal demand management, and evidence-based planning while offering practical insights relevant for transport authorities grappling with tourism seasonality. As cities worldwide confront challenges associated with tourism intensity and seek pathways toward sustainable urban mobility, understanding how transport systems respond to predictable demand variations represents an important dimension of planning practice deserving continued empirical and theoretical attention. The tension between service stability and demand responsiveness will likely persist as a fundamental planning challenge, with different cities reaching different resolutions based on their specific contexts, priorities, and constraints. Enhanced data infrastructure and analytical capabilities create opportunities for more sophisticated approaches to seasonal planning, though whether these opportunities translate into substantively different planning practices remains an empirical question requiring ongoing investigation.

Abbreviations

ATM: Autoritat del Transport Metropolità, CEI: Cost-effectiveness Index, GTFS: General Transit Feed Specification, IDESCAT: Institut d'Estadística de Catalunya, OECD: Organisation for Economic Co-operation and Development, SQL: Structured Query Language, TMB: Transports Metropolitans de Barcelona.

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Author Contributions

Ahmet Alkan Çelik: conceptualisation, data curation, formal analysis, methodology, writing—original draft, Yavuz Selim Balcıoğlu: conceptualisation, methodology, supervision, writing—review and editing, Erkut Altındağ: project administration, supervision, validation, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest that could have influenced the research presented in this manuscript.

Data Availability

The GTFS data used in this study are publicly available from the Mobility Database (https://database.mobilitydata.org/). Tourism statistics are freely accessible from the Institut d'Estadística de Catalunya (https://www.idescat.cat/). Processed analytical datasets and code are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

During the preparation of this manuscript, the authors did not use any generative AI or AI-assisted technologies for writing, data analysis, or interpretation of results. All intellectual content is solely the work of the authors.

Ethics Approval

This study was conducted exclusively using publicly available, aggregated, and anonymised data obtained from official governmental and transport authority sources. No personally identifiable information was collected or processed. Accordingly, formal ethics committee approval was not required.

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References

1. Florido-Benítez L. The close complementarity of museums and theme parks as a tourist package in European capital cities. EJMS. 2024;29(2):211-248. doi: 10.1108/ejms-07-2023-0050
2. Lin Z, Cao Y, Liu H, Li J, Zhao S. Research on Optimization of Urban Public Transport Network Based on Complex Network Theory. Symmetry. 2021;13(12):2436. doi: 10.3390/sym13122436
3. Bok J, Kwon Y. Comparable Measures of Accessibility to Public Transport Using the General Transit Feed Specification. Sustainability. 2016;8(3):224. doi: 10.3390/su8030224
4. Manandhar B, Dunkel Vance K, Rawat DB, Yilmaz N. Leveraging Digital Twin Technology for Sustainable and Efficient Public Transportation. Applied Sciences. 2025;15(6):2942. doi: 10.3390/app15062942
5. Liyanage S, Dia H. An Agent-Based Simulation Approach for Evaluating the Performance of On-Demand Bus Services. Sustainability. 4117;12(1):0. doi: 10.3390/su12104117
6. Kumar BA, Prasath GH, Vanajakshi L. Dynamic Bus Scheduling Based on Real-Time Demand and Travel Time. Int J Civ Eng. 2019;17(9):1481-1489. doi: 10.1007/s40999-019-00445-y
7. Winter K, Cats O, Martens K, Van Arem B. Relocating shared automated vehicles under parking constraints: assessing the impact of different strategies for on-street parking. Transportation. 2020;48(4):1931-1965. doi: 10.1007/s11116-020-10116-w
8. Melo S, Gomes R, Abbasi R, Arantes A. Demand-Responsive Transport for Urban Mobility: Integrating Mobile Data Analytics to Enhance Public Transportation Systems. Sustainability. 4367;16(1):1. doi: 10.3390/su16114367
9. Brizon LC, Caetano JA, De Oliveira CM, Orrico Filho RD. BRT Systems in Brazil: Technical Analysis of Advances, Challenges, and Operational Gaps. Urban Science. 2025;9(10):414. doi: 10.3390/urbansci9100414
10. Scuttari A, Lucia MD, Martini U. Integrated planning for sustainable tourism and mobility. A tourism traffic analysis in Italy's South Tyrol region. Journal of Sustainable Tourism. 2013;21(4):614-637. doi: 10.1080/09669582.2013.786083
11. Kwag SI, Hur U, Ko YD. Sustainable Electric Personal Mobility: The Design of a Wireless Charging Infrastructure for Urban Tourism. Sustainability. 2021;13(3):1270. doi: 10.3390/su13031270
12. Gao Z, Zeng H, Zhang X, *et al.* Exploring tourist spatiotemporal behavior differences and tourism infrastructure supply-demand pattern fusing social media and nighttime light remote sensing data. International Journal of Digital Earth. 2024;17():1. doi: 10.1080/17538947.2024.2310723
13. Wei K, Jiang X, Zhu R, Duan X, Yang J. Spatial and Temporal Distribution Characteristics of Heritage Buildings in Yangzhou and Influencing Factors and Tourism Development Strategies. Buildings. 2025;15(7):1081. doi: 10.3390/buildings15071081
14. Virkar AR. A Review of Dimensions of Tourism Transport affecting Tourist Satisfaction. Indian Journal of Commerce & Management Studies. 2018;9(1):72. doi: 10.18843/ijcms/v9i1/10
15. Liu S, Zhang J, Liu P, Xu Y, Xu L, Zhang H. Discovering spatial patterns of tourist flow with multi-layer transport networks. Tourism Geographies. 2020;25(1):113-135. doi: 10.1080/14616688.2020.1850849
16. Aparicio JT, Arsenio E, Henriques R. Understanding the Impacts of the COVID-19 Pandemic on Public Transportation Travel Patterns in the City of Lisbon. Sustainability. 8342;13(1):5. doi: 10.3390/su13158342
17. Alessandretti L, Natera Orozco LG, Saberi M, Szell M, Battiston F. Multimodal urban mobility and multilayer transport networks. Environment and Planning B: Urban Analytics and City Science. 2022;50(8):2038-2070. doi: 10.1177/23998083221108190
18. Kumar A, Vohra R. Impact of Deep Learning Models for Technology Sustainability in Tourism Using Big Data Analytics. Springer Nature Singapore. 2023:83-96. doi: 10.1007/978-981-19-5723-9_6
19. Silveira-Santos T, Rangel T, Gomez J, Vassallo JM. Forecasting Moped Scooter-Sharing Travel Demand Using a Machine Learning Approach. Sustainability. 5305;16(1):3. doi: 10.3390/su16135305
20. Sugimoto K, Ota K, Suzuki S. Visitor Mobility and Spatial Structure in a Local Urban Tourism Destination: GPS Tracking and Network analysis. Sustainability. 2019;11(3):919. doi: 10.3390/su11030919
21. Aranburu I, Plaza B, Esteban M. Sustainable Cultural Tourism in Urban Destinations: Does Space Matter?. Sustainability. 2016;8(8):699. doi: 10.3390/su8080699
22. Bauder M, Freytag T. Visitor mobility in the city and the effects of travel preparation. Tourism Geographies. 2015;17(5):682-700. doi: 10.1080/14616688.2015.1053971
23. Krishnan S, Aydin NY, Comes T. TIMEWISE: Temporal Dynamics for Urban Resilience - theoretical insights and empirical reflections from Amsterdam and Mumbai. npj Urban Sustain. 2024;4:1. doi: 10.1038/s42949-024-00140-5
24. Calle-Vaquero MDL, García-Hernández M, Mendoza De Miguel S. Urban Planning Regulations for Tourism in the Context of Overtourism. Applications in Historic Centres. Sustainability. 2020;13(1):70. doi: 10.3390/su13010070
25. Ruggieri G, Platania M. Islands' Tourism Seasonality: A Data Analysis of Mediterranean Islands' Tourism Comparing Seasonality Indicators (2008-2018). Sustainability. 2024;16(9):3674. doi: 10.3390/su16093674
26. Riganti P, Nijkamp P. Congestion in Popular Tourist Areas: A Multi-Attribute Experimental Choice

Analysis of Willingness-to-Wait in Amsterdam. Tourism Economics. 2008;14(1):25-44. doi: 10.5367/000000008783554785
27. Mazzola F, Cirà A, Ruggieri G, Butler R. Air transport and tourism flows to islands: A panel analysis for southern European countries. Journal of Tourism Research. 2022;24(5):639-652. doi: 10.1002/jtr.2527
28. Banerjee A, Mahmudov T, Adler E, Aisyah FN, Wörndl W. Modeling sustainable city trips: integrating CO2e emissions, popularity, and seasonality into tourism recommender systems. Inf Technol Tourism. 2025;27(1):189-226. doi: 10.1007/s40558-024-00303-1
29. Cavallaro F, Ciari F, Nocera S, Prettenthaler F, Scuttari A. The impacts of climate change on tourist mobility in mountain areas. Journal of Sustainable Tourism. 2016;25(8):1063-1083. doi: 10.1080/09669582.2016.1253092
30. Cheung KS, Li LH. Understanding visitor-resident relations in overtourism: developing resilience for sustainable tourism. Journal of Sustainable Tourism. 2019;27(8):1197-1216. doi: 10.1080/09669582.2019.1606815
31. Andriotis K. Seasonality in Crete: Problem or a Way of Life?. Tourism Economics. 2005;11(2):207-224. doi: 10.5367/0000000054183478
32. Liu Y, Feng G, Chin KS, Sun S, Wang S. Daily tourism demand forecasting: the impact of complex seasonal patterns and holiday effects. Current Issues in Tourism. 2023 ;26(10):1573-1592. doi: 10.1080/13683500.2022.2060067
33. Peungnumsai A, Miyazaki H, Witayangkurn A, Kim SM. A Grid-Based Spatial Analysis for Detecting Supply–Demand Gaps of Public Transports: A Case Study of the Bangkok Metropolitan Region. Sustainability. 1038;12(2):4. doi: 10.3390/su122410382
34. Zheng W, Li J, Li C. Tourism demand forecasting using complex network theory. Asia Pacific Journal of Tourism Research. 2024; ahead-of-print(ahead-of-print):302-320. doi: 10.1080/10941665.2024.2324536
35. Bauchinger L, Reichenberger A, Goodwin-Hawkins B, Kobal J, Hrabar M, Oedl-Wieser T. Developing Sustainable and Flexible Rural–Urban Connectivity through Complementary Mobility Services. Sustainability. 2021;13(3):1280. doi: 10.3390/su13031280
36. Navidi Z, Ronald N, Winter S. Comparison between ad-hoc demand responsive and conventional transit: a simulation study. Public Transp. 2017;10(1):147-167. doi: 10.1007/s12469-017-0173-z
37. Aqib M, Mehmood R, Alzahrani A, Katib I, Albeshri A, Altowaijri SM. Rapid Transit Systems: Smarter Urban Planning Using Big Data, In-Memory Computing, Deep Learning, and GPUs. Sustainability. 2736;11(1): 2736. doi: 10.3390/su11102736
38. Tiwari S, Nassir N, Lavieri PS. Smart Insertion Strategies for Sustainable Operation of Shared Autonomous Vehicles. Sustainability. 2024; 16(12): 5175. doi: 10.3390/su16125175
39. Diab EI, Badami MG, El-Geneidy AM. Bus Transit Service Reliability and Improvement Strategies: Integrating the Perspectives of Passengers and Transit Agencies in North America. Transport Reviews. 2015;35(3):292-328. doi: 10.1080/01441647.2015.1005034
40. Wong J. Leveraging the General Transit Feed Specification for Efficient Transit Analysis. Transportation Research Record: Journal of the Transportation Research Board. 2013;2338(1):11-19. doi: 10.3141/2338-02
41. Stępniak M, Goliszek S. Spatio-Temporal Variation of Accessibility by Public Transport: The Equity Perspective. The Rise of Big Spatial Data. Springer. 2016:241-261. doi: 10.1007/978-3-319-45123-7_18
42. Stępniak M, Pritchard JP, Geurs KT, Goliszek S. The impact of temporal resolution on public transport accessibility measurement: Review and case study in Poland. Journal of Transport Geography. 2019;75: 8–24. doi: 10.1016/j.jtrangeo.2019.01.007
43. Ma X, Yang Z, Zheng J. Analysis of spatial patterns and driving factors of provincial tourism demand in China. Sci Rep. 2022;12:1. doi: 10.1038/s41598-022-04895-8
44. Wessel N, Farber S. On the accuracy of schedule-based GTFS for measuring accessibility. J Transp Land Use. 2019;12(1). doi: 10.5198/jtlu.2019.1502
45. Hörcher D, Tirachini A. A review of public transport economics. Econ Transp. 2021;25:100196. doi: 10.1016/j.ecotra.2021.100196
46. Diana M, Quadrifoglio L, Pronello C. A methodology for comparing distances traveled by performance-equivalent fixed-route and demand responsive transit services. Transportation Planning and Technology. 2009;32(4):377-399. doi: 10.1080/03081060903119618
47. Neutens T, Schwanen T, Witlox F, De Maeyer P. Evaluating the Temporal Organization of Public Service Provision Using Space-Time Accessibility Analysis. Urban Geography. 2010;31(8):1039-1064. doi: 10.2747/0272-3638.31.8.1039
48. Kommineni M, Baseer KK. An Architecture and Review of Intelligence Based Traffic Control System for Smart Cities. EAI Endorsed Trans Energy Web. 2024;11. doi: 10.4108/ew.4964
49. Lunke EB. Commuters' satisfaction with public transport. J Transp Health. 2020;16: 100842. doi: 10.1016/j.jth.2020.100842
50. del Castillo AC, Parlikad AK. Dynamic fleet management: Integrating predictive and preventive maintenance with operation workload balance to minimise cost. Reliability Engineering & System Safety. 2024; 249: 110243. doi: 10.1016/j.ress.2024.110243
51. Kumar P, Ekka P. Statistical analysis of the impacts of COVID-19 pandemic on the small and large-scale tourism sectors in developing countries. Environ Dev Sustain. 2023;26(4):9625-9659. doi: 10.1007/s10668-023-03112-4

52. Lai IKW, Hitchcock M, Lu D, Liu Y. The Influence of Word of Mouth on Tourism Destination Choice: Tourist–Resident Relationship and Safety Perception among Mainland Chinese Tourists Visiting Macau. Sustainability. 2018;10(7):2114. doi: 10.3390/su10072114

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