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Time-Aware Multi-Day Tourist Routing for Cappadocia: A Time-Window Orienteering Model with an Opportunity Score for Surfacing Overlooked Attractions

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Abstract

Designing a realistic multi-day itinerary for a heritage destination is harder than minimizing travel distance: attractions have opening hours, some experiences are valid only within narrow daily windows, each stop consumes a different amount of time, and the visitor's day is finite. Existing work on Cappadocia derives attraction centres from social-media data and connects them with a plain travelling-salesman tour that ignores time. Executed against real opening hours, that distance-optimal tour arrives at eight attractions after closing, never catches the balloon at sunrise, mistimes all five sunset viewpoints, and spreads across seven days. We instead formulate the problem as a Team Orienteering Problem with Time Windows (TOPTW) over a real OpenStreetMap road network, with service times, opening hours, a daily budget and destination-specific temporal rules, and produce feasible 2-, 3- and 4-day plans. Attractiveness is grounded in 2025 Wikipedia pageviews cross-checked with official visitor statistics and extended by a documented type prior. An opportunity score rewards low-profile attractions near a popular hub: raising its weight lowers the mean popularity of the visited set from 0.41 to 0.06, raises the share of lesser-known stops from 52% to 100% and reduces driving time, making visitor dispersal an explicit, tunable objective.

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Contribution to the field statement:

This study turns visitor dispersal into an optimizable term of a tourist-routing objective. It combines real opening hours, service times and destination-specific temporal rules with an open-data attractiveness index, showing that distance-optimal tours of Cappadocia are temporally infeasible and that a tunable opportunity score disperses visits while reducing driving.

Highlights:

- A TOPTW model builds time-feasible 2-, 3- and 4-day Cappadocia itineraries
- The distance-optimal prior tour reaches eight attractions after closing
- Popularity is anchored in 2025 official visitor counts and Wikipedia views
- Opportunity weight cuts mean popularity 0.41 to 0.06 and driving by 68%

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1. Introduction

Distance-optimal routes are not necessarily executable itineraries; in heritage destinations such as Cappadocia, time windows and experience timing are part of the attraction itself. This premise motivates our approach.

Cappadocia is one of Türkiye's most visited cultural and natural destinations, featuring dozens of distinct attractions, such as open-air rock-cut churches, underground cities, fairy-chimney valleys, sunrise hot-air-balloon flights, and sunset viewpoints, within a compact area. For an independent visitor with two to four days, the



practical question is not which attractions exist but which to visit, on which day, and in what order, given that many experiences are only meaningful or even accessible at particular times.

This temporal organization is central to the problem addressed in this study. A balloon flight happens at dawn and must be the first activity of its day. Underground cities such as Derinkuyu and Kaymaklı close in the late afternoon. Sunset viewpoints are worthwhile only in the evening. Museums and monasteries follow opening hours. Each stop takes a characteristic amount of time (twenty minutes for a small chapel, two hours for an open-air museum) and a comfortable touring day runs from morning to early evening. A plan that ignores these facts is not a plan at all.

Prior work on the same destination [1] used a decade of geotagged Flickr photographs to cluster the region into attraction centres and then computed a single distance-minimizing travelling-salesman (TSP) tour through all of them, but is silent on time. As shown in Section 3, the resulting tour is temporally infeasible: followed against real opening hours it reaches eight attractions after closing, never times the balloon at sunrise, mistimes every sunset viewpoint, and requires seven days. This is not a flaw of the prior work, whose goal was attraction-centre detection and route generation, but a limitation of distance-only routing when it is used directly as a visitor itinerary.

This study makes two main contributions. First, a time-aware, multi-day itinerary model for Cappadocia, cast as a Team Orienteering Problem with Time Windows (TOPTW) over a real OpenStreetMap (OSM) driving network, with per-attraction service times, opening and closing windows, a daily budget, and destination-specific temporal rules (balloon-first-at-sunrise, underground-city closing, sunset windows); the model selects and schedules a high-value subset of attractions across two to four days, guaranteeing temporal feasibility by construction. Second, an opportunity (“hidden-gem”) score for sustainable visitor distribution that rewards low-profile points close to a popular hub and quick to visit; tuning its weight shifts the itinerary from a popularity tour towards a discovery tour that surfaces overlooked attractions, and we quantify this shift as a lever for over-tourism mitigation [2, 3]. Attractiveness is grounded in real open data where available (Wikipedia pageviews cross-checked with official visitor statistics, extended by a documented type prior), addressing the central risk that a routing model be driven by unverified inputs.

1.1. The orienteering problem and the tourist trip design problem

Personalized itinerary planning is most often formalized as the Orienteering Problem (OP) and its tourism specialization, the Tourist Trip Design Problem (TTDP), in which a high-value subset of points of interest (POIs) is selected and sequenced under time and budget limits. The orienteering problem and its team and time-window variants are surveyed by Vansteenwegen et al. [4]; Gavalas et al. [5] classify TTDP formulations together with the solution approaches used for them. The model developed here is a multi-day TOPTW in that lineage. Sylejmani et al. [6] extend the Multi-Constrained Team OPTW with attraction-pattern constraints and solve it with iterated local search. Dinç Yalçın et al. [7] enrich the TTDP with budget, weather and break constraints and deliver a mobile application for a Turkish city (Eskişehir). Cura [8] proposes a hybrid metaheuristic for the clustered OP, and TSP machinery continues to evolve, including a polynomial-time approximation scheme for the Euclidean TSP with soft time windows [9] and hybrid and mutation heuristics [10, 11], relevant because our baseline (Section 3.1) is a plain TSP.

1.2. Time windows, road-network realism and open data for attraction popularity

Realistic itineraries must respect when travel and visits happen, not only how far points are. Jaballah et al. [12] show that the precision of the road-network representation materially affects time-dependent routing, supporting our use of a real OSM driving network. Our model adds destination-specific temporal structure rarely treated jointly in the tourism-OP literature: a dawn-only, first-scheduled balloon, afternoon-closing underground cities, and evening-only sunset viewpoints.

Geotagged social-media data, and Flickr in particular, is a standard source for detecting attractions and estimating popularity. Kádár and Ribeiro Martins [13] argue that Flickr's open application programming interface (API) uniquely enabled reproducible, cross-destination analyses, while Lee and Kang [14] and Lin et al. [15] mine Flickr for destinations, preferences and cultural-route visitation, finding heritage attractions act as anchors and noting the inherent bias towards already-popular sites. Rather than a photo-based layer, which requires per-POI API access and is left to future work (Section 2.4), we build popularity from two open signals, Wikipedia pageviews (Wikimedia Analytics) [16] and official visitor statistics [17], and explicitly counteract the popularity bias through our opportunity score.

1.3. GIS-based, learning-based and sustainable route design: the gap

Geographic Information System (GIS) and learning approaches design tourist routes at regional and heritage scales: Güngör et al. [18] for a district of Ankara (Türkiye), Zhao et al. [19] for a geopark, with Kızılkın et al. [20] mapping sustainable-development priorities across Türkiye's geopark areas, and Noorian [21] and Yan et al. [22] for personalized and heritage-aware recommendation coupled with sustainable site management; the wider smart-tourism technology literature is collected in edited volumes such as Rocha et al. [23]. On sustainability, Divsalar et al. [24] formulate a green TTDP minimizing transport emissions. Over-tourism itself is well theorized on the tourism side: Koens et al. [2] show that its impacts are experienced unevenly across a destination and are driven as much by visitor concentration as by visitor numbers, and the European Parliament policy review of



Peeters et al. [3] lists spatial dispersal of visitors among the principal responses available to destination managers. However, the demand-side problem of over-tourism and visitor dispersal, that is, steering visitors away from congested icons towards accessible, overlooked attractions, is not addressed within the itinerary-optimization objective itself. Our contribution is a faithful, open-data, time-aware multi-day instantiation for a real heritage destination, plus an explicit opportunity score that turns visitor dispersal into a tunable term of that objective.

2. Method

2.1. Study area and points of interest

The study covers the Cappadocia region around Nevşehir. After removing duplicates and one out-of-region erroneous record we obtain 65 points of interest (POIs) plus a depot. Ürgüp town centre is the single start and end node for every daily tour, reflecting central lodging. A synthetic activity node, Balloon flight (Göreme), represents the sunrise balloon experience. The working set is 67 nodes (depot, 65 POIs and the balloon).

2.2. Attraction attributes: service times and time windows

Each POI is typed (open-air museum, underground city, church, monastery, valley, castle, museum, viewpoint, town centre and so on); the type sets a representative service time and opening and closing window (Table 1). Three destination-specific temporal rules are encoded: the balloon has a sunrise window (05:30–07:30) and must be first; underground cities close in the late afternoon (08:00–17:00); and famous sunset viewpoints are flagged for the evening. Windows are modelling assumptions based on representative public operating schedules; the full per-POI assignment is listed in Appendix A.

Table 1. Representative service times and time windows by attraction type.

Attraction type	Service (min)	Opening-closing	Note
Underground city	60	08:00–17:00	Derinkuyu, Kaymaklı, Mazi, Tatların
Open-air museum	120	08:00–18:00	Göreme Open-Air Museum
Church / chapel	20	08:00–18:00	Short visit; favoured by opportunity score
Valley	90	06:00–20:00	Daylight-dependent walking
Castle	45	08:00–19:00	Uçhisar, Ortahisar, Nevşehir
Museum	45	08:00–18:00	—
Viewpoint	45	06:00–20:00	Fairy chimneys, Üç Güzeller
Town centre	60	06:00–22:00	Göreme, Avanos, Ortahisar
Balloon	120	05:30–07:30	First activity of the day

2.3. Road-network travel times

Inter-POI travel is computed on a real OpenStreetMap driving network. The drivable graph for the region (approximately 23,000 nodes and 63,000 directed edges) is retrieved with OSMnx [25]; each POI is snapped to its nearest network node and pairwise shortest paths give a 67×67 travel-time and distance matrix. Representative values are realistic (Ürgüp to Göreme approximately 11–16 min; Ürgüp to Derinkuyu approximately 39 min; Ürgüp to Ihlara approximately 88 min). Open OSM data makes the pipeline fully reproducible.

2.4. Attractiveness: a real-data popularity index

Popularity $Pop_i \in [0,1]$ is grounded in real 2025 open data rather than a synthetic proxy. Two complementary signals are used. Official visitor statistics for the region's ticketed sites (Ministry of Culture and Tourism figures relayed by the provincial administration) [17] provide a direct measure of physical visitation. Wikipedia pageviews (Wikimedia Analytics API, all-access, user agent, 2025) [16] provide an open, reproducible measure of digital interest for POIs with an article (Table 2). We combine the two on a common logarithmic scale, giving priority to official visitation where available and discounting digital-only signals; the 56 minor POIs without either signal receive a documented, lower-band type prior. The result is a transparent index in which 9 of 65 POIs are anchored to real data (four to official visitation, of which three also to pageviews, and five to pageviews only) and the remainder are typed estimates, each POI carrying its data-source label.

Table 2. Real 2025 popularity signals used to anchor the attractiveness index (excerpt).

POI / article	Official visitors 2025	Wikipedia pageviews 2025	Signal used
Göreme Open-Air Museum	1,187,016	919	official (+wiki)
Paşabağ / fairy chimneys	907,345	—	official
Kaymaklı Underground City	688,417	16,334	official (+wiki)



Derinkuyu	547,417	396,530	official (+wiki)
Underground City			
Göreme (town)	—	40,981	wiki
Uçhisar	—	26,135	wiki
Avanos	—	13,756	wiki
Love Valley (Aşıklar)	—	11,036	wiki
Ihlara	—	6,194	wiki

Reliability. The two signals measure different things and are not interchangeable: official statistics capture ticketed physical visitation, whereas pageviews capture online information-seeking, and are affected by article naming, redirects and language. The clearest example is the Göreme Open-Air Museum, which ranks first in physical visitation (approximately 1.19 million) yet draws few views on its specific article (visitors search “Cappadocia” or “Göreme” instead), while Derinkuyu attracts both high visitation and high curiosity. We therefore treat pageviews as a digital-visibility proxy, use official visitation as the primary anchor where available, and report both. Because per-POI Flickr counts require an API key and Instagram and TikTok now dominate travel imagery, a photo-based layer is left to future work; the pipeline accepts such counts without model changes.

2.5. Composite attractiveness score

Each POI is scored by the composite attractiveness score of Equation (1), in which $\alpha + \beta = 1$, Pop_i is the real-data popularity index of Section 2.4 and Opp_i is the opportunity term.

$$S_i = \alpha \cdot \text{Pop}_i + \beta \cdot \text{Opp}_i \quad (1)$$

The opportunity term rewards a low-profile attraction that is close to a popular hub and quick to visit. It combines three components. The kernel-weighted popularity of the surroundings, Equation (2), accumulates the popularity of every other POI j discounted by travel time t_{ij} , with τ an influence scale.

$$H_i = \sum_{j \neq i} \text{Pop}_j \cdot \exp\left(-\frac{t_{ij}}{\tau}\right) \quad (2)$$

The under-valuation contrast, Equation (3), is high only when the surroundings are popular but the point itself is not; $\hat{H}_i$ denotes H_i rescaled to the unit interval.

$$C_i = \max(0, \hat{H}_i - \text{Pop}_i) \quad (3)$$

The short-visit reward, Equation (4), favours quick stops, where d_i is the service time of POI i and d_0 a reference duration.

$$g_i = \exp\left(-\frac{d_i}{d_0}\right) \quad (4)$$

The opportunity score is the product of the three components, Equation (5), in which the exponent p controls how strongly proximity to a popular hub is weighted. Opp_i is normalized to $[0,1]$ with the depot excluded.

$$\text{Opp}_i = (\hat{H}_i)^p \cdot C_i \cdot g_i \quad (5)$$

Opp_i is route-independent and pre-computed, so it enters the optimizer as a constant. The weight β is a managerial dial: $\beta = 0$ reproduces a popularity-only itinerary, while a larger β promotes accessible overlooked points.

2.6. TOPTW model

Sets and parameters. N is the set of POIs, 0 the depot, $V = N \cup \{0\}$, and $D = \{1, \dots, m\}$ the days. Each POI i has score S_i , service time d_i and time window $[o_i, c_i]$; each ordered pair (i, j) has OSM travel time t_{ij} ; each day operates within $[E, L]$. $B \subset N$ denotes balloon activities and $W \subset N$ the sunset viewpoints, which carry evening windows.

Decision variables. $x_{ijd} \in \{0,1\}$ is 1 if arc $i \rightarrow j$ is used on day d ; $y_{id} \in \{0,1\}$ is 1 if POI i is served on day d ; $a_{id} \geq 0$ is the service-start time of i on day d ; the depot start and return times of day d are a_{0d}^{start} and a_{0d}^{end} . M is a sufficiently large constant.

The objective, Equation (6), maximizes the composite attractiveness collected over the planning horizon.

$$\max \sum_{d \in D} \sum_{i \in N} S_i \cdot y_{id} \quad (6)$$

Assignment and routing are governed by Equations (7) to (9). Each POI is served at most once across all days, Equation (7); each day departs from and returns to the depot, Equation (8); and flow is conserved at every served POI, Equation (9).

$$\sum_{d \in D} y_{id} \leq 1, \quad \forall i \in N \quad (7)$$

$$\sum_{j \in V} x_{0jd} = \sum_{i \in V} x_{i0d} = 1, \quad \forall d \in D \quad (8)$$

$$\sum_{i \in V} x_{ijd} = \sum_{k \in V} x_{jkd} = y_{jd}, \quad \forall j \in N, \forall d \in D \quad (9)$$

Time propagation follows the big-M form of Equation (10): if arc $i \rightarrow j$ is used on day d , the service-start time of j is at least that of i plus the service time of i and the travel time between them. Opening hours are imposed conditionally by Equation (11), so that an unvisited POI is left unconstrained; early arrival is permitted with waiting.

$$a_{jd} \geq a_{id} + d_i + t_{ij} - M(1 - x_{ijd}), \quad \forall i, j \in V, \forall d \in D \quad (10)$$

$$o_i - M(1 - y_{id}) \leq a_{id} \leq c_i + M(1 - y_{id}), \quad \forall i \in N, \forall d \in D \quad (11)$$

The daily touring budget is set by Equation (12), and the optional cardinality limit of Equation (13) caps stops per day for visitor comfort.



$$a_{0d}^{\text{start}} \geq E, \quad a_{0d}^{\text{end}} \leq L \quad (12)$$

$$\sum_{i \in N} y_{id} \leq K_{\max}, \quad \forall d \in D \quad (13)$$

Destination-specific rules complete the model. A balloon activity, if chosen, lies in its sunrise window ($o_b = 05:30$, $c_b = 07:30$) and precedes every other stop of that day, Equation (14). Sunset viewpoints carry evening windows $[o_w, c_w] = [18:30, 20:00]$, Equation (15), which confine them to the end of the day. Feasibility with respect to opening hours is therefore guaranteed by construction. We present this as the conceptual optimization problem; the implemented solver (Section 2.7) uses the OR-Tools routing abstraction, a heuristic, rather than an exact mixed-integer solve.

$$a_{bd} \leq a_{jd} + M(1 - y_{bd}), \quad \forall b \in B, \forall j \in N \quad (14)$$

$$o_w \leq a_{wd} \leq c_w, \quad \forall w \in W \quad (15)$$

2.7. Solution method

We solve the model with the Google OR-Tools routing layer. Each day is a vehicle; optional visits are modelled by node disjunctions whose drop penalty equals the score S_i scaled by 10^5 , so that minimizing dropped penalties maximizes collected attractiveness while arc costs (travel time) break ties towards shorter routes. A time dimension accumulates travel plus service time; time-window ranges are imposed on the cumulative service-start variable; a per-day cardinality dimension caps stops at $K_{\max} = 7$; and a 05:30 earliest vehicle start together with the balloon's sunrise window makes a dawn balloon feasible. Search uses a path-cheapest-arc construction followed by guided local search.

Stability and reproducibility. The procedure is deterministic and converges quickly: on the full 67-node instance the 3-day composite objective is identical (7.92, matching the 3-day package in Table 4) at time limits of 3, 8 and 20 seconds, so results are not sensitive to the budget and are reported from a single run. Exact solution of a TOPTW of this size is not practical within an interactive time budget, and the reference heuristic family for the problem is iterated local search [26], the scheme also used by Sylejmani et al. [6]; the guided local search applied here rests on the same neighborhood-based principle and is adopted for its determinism and ease of deployment. The method does not certify global optimality; on reduced instances the guided-local-search objective matches that of much longer runs, indicating near-optimal, stable solutions. The entire pipeline (data preparation, scoring, solving and map rendering) is implemented in Python and reproducible from open inputs.

3. Results

3.1. Baselines: why time and attractiveness both matter

We compare against two baselines. The first reproduces the prior approach: a distance-optimal plain TSP through all 66 POIs with no time windows. Because the prior pipeline proposes a single all-POI tour, we execute that tour on an 08:00–19:00 daily schedule (a standard touring day), carrying unfinished travel to the next morning, and record where real opening hours are violated. The tour is distance-efficient (approximately 770 min driving and approximately 67 h with activities) but temporally broken (Table 3): it arrives at eight attractions after closing, never times the balloon at sunrise, mistimes all five sunset viewpoints, and spans seven days (Figure 1). The second baseline is a distance-only feasible TOPTW that ignores attractiveness (uniform scores): although temporally feasible, it collects only 2.30 units of real popularity ($\sum \text{Pop}_i$) over a 3-day plan, versus 8.60 for the popularity-aware model ($\beta = 0$), so attractiveness-awareness matters as much as feasibility.

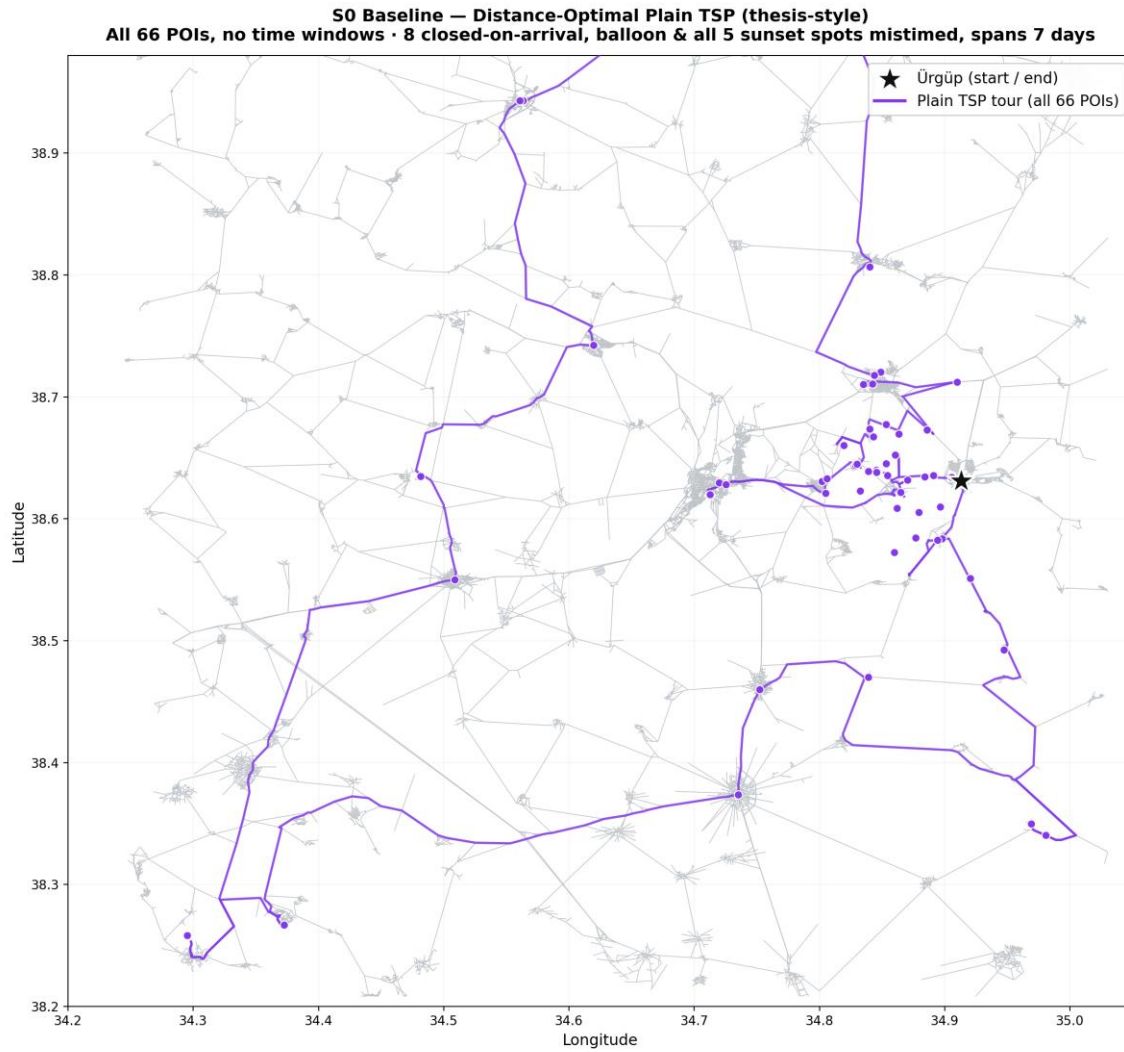


Figure 1. Distance-optimal plain TSP through all POIs (baseline). Distance-efficient but temporally infeasible against real opening hours.

Table 3. Plain TSP and distance-only baselines versus the proposed TOPTW model.

Criterion	Plain TSP	TOPTW (ours)
Time windows considered	No	Yes
Closed-on-arrival attractions	8	0
Balloon at sunrise	No	Yes ($\approx 07:00$)
Sunset viewpoints correctly timed	0 of 5	enforced by window
Daily 08:00–19:00 structure	No (spans 7 days)	Yes
Real popularity collected, ΣPop_i (3-day)	—	8.60 ($\beta=0$) vs 2.30 (distance-only)

3.2. Feasible 2-, 3- and 4-day plans

Unless stated otherwise we report the discovery-oriented configuration $\beta = 0.6$ (Section 3.4 varies β). The TOPTW model produces temporally valid packages with zero time-window violations by construction, the balloon at sunrise as the first activity, and a daily return to Ürgüp. Collected attractiveness increases with the day budget (Table 4). Figures 2 to 4 present the plans as metro-style maps in which each day is a coloured line of numbered stations, with a zoom inset for the dense Göreme, Avanos and Ürgüp core and an accompanying station index; the format is directly usable by visitors and destination information services.

Table 4. Feasible TOPTW packages at $\beta = 0.6$ (seven stops per day; zero window violations; balloon at sunrise).

Package	POIs visited	Composite attractiveness objective S ($\beta = 0.6$)
2 days	14	6.33
3 days	21	7.92
4 days	28	9.05

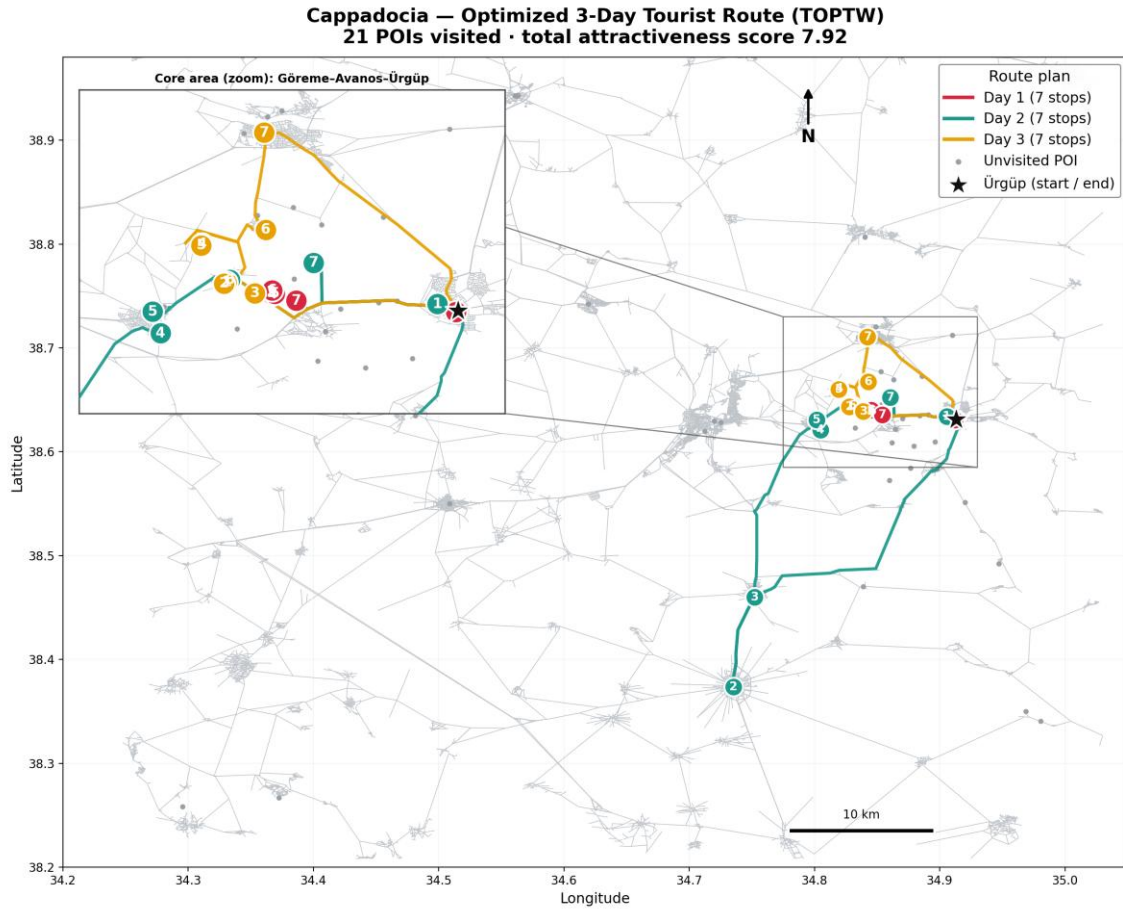


Figure 2. Optimized 3-day route (metro-map style) with a zoom inset of the core area.

Station index — Cappadocia 3-Day Route

Day 1	Day 2	Day 3
1 Ürgüp Kiliseleri	1 Asmalı Konak	1 Göreme
2 Aziz Basil Şapeli	2 Derinkuyu	2 Balon Turu (Göreme)
3 Elmalı Kilisesi	3 Kaymaklı	3 El Nazar Kilisesi
4 Yılanlı Kilise(Kalesi)	4 Güllüdere Kilisesi(Çavuşin)	4 Aşıklar Vadisi
5 Karanlık Kilise	5 Uçhisar Kalesi	5 Peribacaları
6 Göreme Açık Hava Müzesi	6 Göreme Roma Kalesi ve Mezarı	6 Vaftizci Yahya Kilisesi(Çavuşin)
7 Fırkatan Kilisesi	7 Üzümlü Kilise	7 Avanos Vadisi

Figure 3. Station index for the 3-day plan.

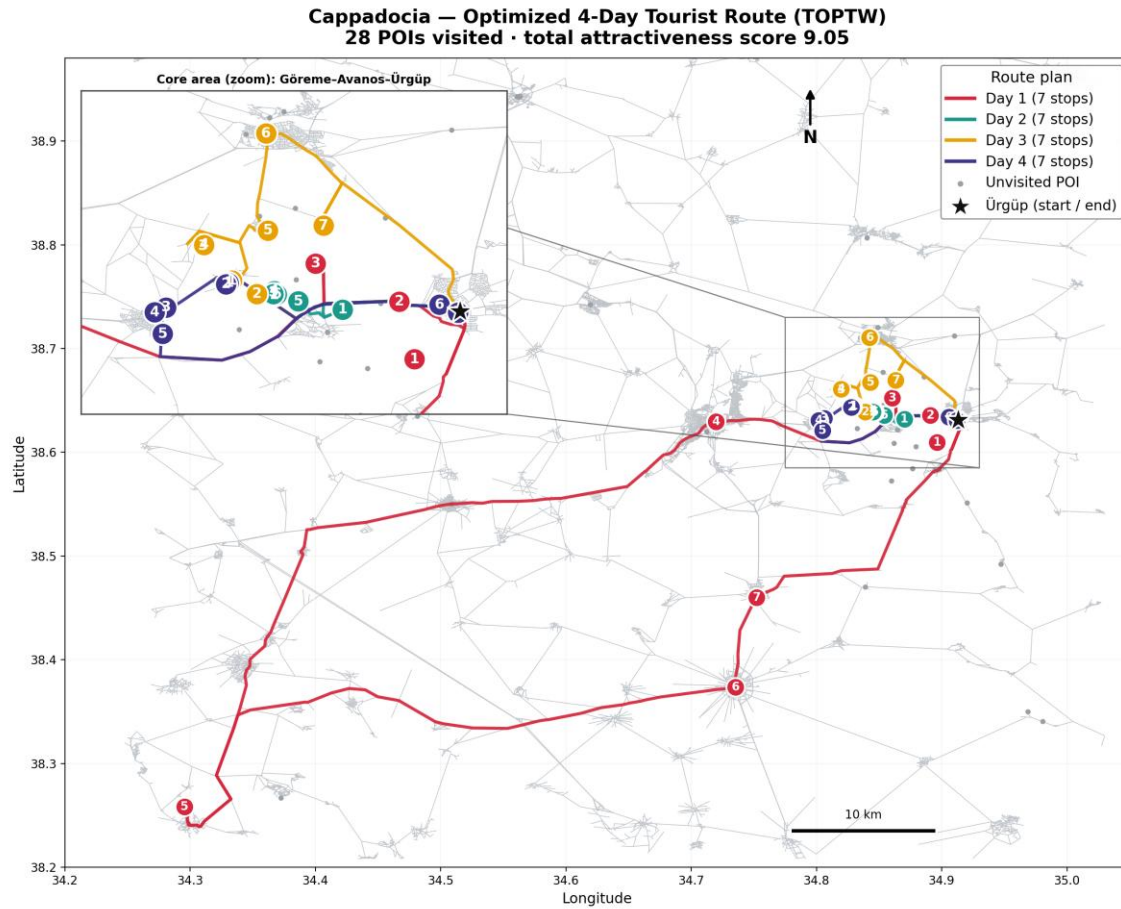


Figure 4. Optimized 4-day route.

3.3. The opportunity score surfaces overlooked attractions

Holding everything else fixed (3-day plan, seven stops per day), we vary β . Moving from $\beta = 0$ (popularity-only) to $\beta = 0.6$ swaps twelve stops: the itinerary drops long, isolated but popular valleys (Gomeda, Devrent, Aşıklar, Zemi and Üzengi, each 90 min and far from the core) and adds short, overlooked churches three to four minutes from a flagship hub (El Nazar, Fırkatan, Karanlık Kilise, Elmalı, Aziz Basil and Güllüdere, each 20 min, with real popularity below 0.10 and no dedicated Wikipedia article). Figure 5 plots every POI in the popularity and opportunity plane: added hidden gems cluster at low popularity and high opportunity, dropped points at high popularity and near-zero opportunity.



Figure 5. Popularity and opportunity plane. Increasing β adds low-popularity, high-opportunity hidden gems (upper left) and drops popular but isolated, long-dwell points (lower right).

3.4. Quantifying visitor dispersal

The opportunity weight has a monotone, quantifiable effect on visitor distribution (Table 5). As β rises from 0 to 1, the mean popularity of the visited set falls from 0.41 to 0.06, the share of lesser-known stops ($\text{Pop} < 0.35$) rises from 52% to 100%, the number of overlooked (type-estimate) POIs visited rises from 11 to 21, and, because the added points are short and clustered near hubs, total driving time falls from 533 to 172 minutes. The opportunity component thus disperses visits from congested icons towards accessible lesser-known sites, operationalizing within the routing objective the dispersal response that the over-tourism literature identifies as a policy option [2, 3], while simultaneously reducing transport, turning over-tourism mitigation into an explicit, tunable objective rather than a rhetorical claim.

Table 5. Visitor-dispersal metrics as a function of the opportunity weight β (3-day plan).

β	Mean popularity	Lesser-known share ($\text{Pop} < 0.35$)	Overlooked POIs visited	Driving time (min)
0.0	0.41	52%	11	533
0.2	0.37	52%	11	330
0.4	0.36	52%	11	334
0.6	0.34	57%	12	216
0.8	0.22	81%	17	224
1.0	0.06	100%	21	172

4. Discussion

Managerial implications. The model is a decision-support tool for destination managers and information services. The day budget and comfort cap encode realistic touring effort; the time windows encode operating reality; and the opportunity weight β is an explicit policy lever whose effect on visitor distribution is quantified in Table 5. Raising β is a low-cost, transparent mechanism to relieve pressure on congested icons and channel visitors, and their spending, towards overlooked points and their communities, with a co-benefit of reduced driving.

Limitations. Popularity is anchored to real 2025 data for the region's principal ticketed sites (official visitation) and for POIs with a Wikipedia article (pageviews), but the 56 minor POIs rely on a documented type prior; extending official or digital coverage to these points would further strengthen the attractiveness layer.



Pageviews measure digital interest rather than physical visitation, as the Göreme Open-Air Museum case makes clear, so the two signals are reported separately rather than merged uncritically. Travel times use the OSM driving network with a speed model rather than live traffic; opening hours follow representative winter assumptions; the time-dependent valuation of sunset experiences, beyond a hard window, and a per-POI Flickr layer are left to future work; and the instance is regional, so very large national instances would motivate dedicated metaheuristics.

5. Conclusion

We presented a time-aware, multi-day tourist-routing model for Cappadocia that, unlike prior distance-only work, produces itineraries feasible against real opening hours, service times, daily budgets and destination-specific temporal experiences, with attractiveness grounded in real open data and an opportunity score whose effect on visitor dispersal is quantified. The approach is lightweight, reproducible, and yields both machine schedules and visitor-facing maps. Future work includes a per-POI Flickr layer and live traffic, time-dependent experience value such as a sunset bonus, group and multi-modal extensions, and field validation with destination-management stakeholders. In short, distance-optimal routes are not necessarily executable itineraries: in heritage destinations, when to visit is part of the attraction itself.

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Conflicts of Interest

The author(s) report no conflicts of interest.

Data Availability Statement

The point-of-interest table (service times, time windows, attractiveness components and per-POI data-source labels), the OpenStreetMap travel-time matrix and the scoring, solver and map-rendering scripts are available at [repository URL or DOI, to be deposited before publication]. Wikipedia pageview counts are retrieved from the public Wikimedia Analytics API [16]; official visitor statistics are as published by the source listed in [17].

Institutional Review Board Statement

Not applicable. The study involves no human participants, animal subjects or personal data.

CRedit Author Statement

Abdullah KARAAĞAÇ: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Data curation; Writing – original draft; Writing – review & editing; Visualization.

References

- [1] Türkan, M. (2024). *Determination of tourism attraction centres and the optimum travel route from social media data: The Cappadocia case* [Master's thesis, Niğde Ömer Halisdemir University].
- [2] Koens, K., Postma, A., & Papp, B. (2018). Is overtourism overused? Understanding the impact of tourism in a city context. *Sustainability*, 10(12), 4384. <https://doi.org/10.3390/su10124384>
- [3] Peeters, P., Gössling, S., Klijs, J., Milano, C., Novelli, M., Dijkmans, C., Eijgelaar, E., Hartman, S., Heslinga, J., Isaac, R., Mitas, O., Moretti, S., Nawijn, J., Papp, B., & Postma, A. (2018). *Research for TRAN Committee: Overtourism – impact and possible policy responses* (PE 629.184). European Parliament, Policy Department for Structural and Cohesion Policies.
- [4] Vansteenwegen, P., Souffriau, W., & Van Oudheusden, D. (2011). The orienteering problem: A survey. *European Journal of Operational Research*, 209(1), 1–10. <https://doi.org/10.1016/j.ejor.2010.03.045>
- [5] Gavalas, D., Konstantopoulos, C., Mastakas, K., & Pantziou, G. (2014). A survey on algorithmic approaches for solving tourist trip design problems. *Journal of Heuristics*, 20(3), 291–328. <https://doi.org/10.1007/s10732-014-9242-5>
- [6] Sylejmani, K., Abdurrahmani, V., Ahmeti, A., & Gashi, E. (2024). Solving the tourist trip planning problem with attraction patterns using meta-heuristic techniques. *Information Technology & Tourism*, 26, 633–678. <https://doi.org/10.1007/s40558-024-00297-w>
- [7] Dinç Yalçın, G., Malta, H., & Saylık, S. (2023). A new mathematical model and a heuristic algorithm for the tourist trip design problem under new constraints: A real-world application. *OPSEARCH*, 60, 1703–1730. <https://doi.org/10.1007/s12597-023-00678-5>
- [8] Cura, T. (2026). A particle swarm optimization algorithm for the clustered orienteering problem. *Journal of Heuristics*, 32, Article 24. <https://doi.org/10.1007/s10732-026-09596-3>
- [9] Song, L., Wu, S., Lai, Y., Liu, C., Huang, H., & Du, H. (2026). PTAS for Euclidean travelling salesman problem with soft time windows. *Journal of Combinatorial Optimization*, 51, Article 13. <https://doi.org/10.1007/s10878-025-01387-z>
- [10] Abu Doush, I., Al-Khatib, R. M., Alotaibi, B., & Alhatamleh, S. (2026). Essential mutation framework for solving travelling salesman problem. *Cluster Computing*, 29, Article 49. <https://doi.org/10.1007/s10586-025-05789-w>



- [11] Singh, D. R., Singh, M. K., Chaurasia, S. N., & Verma, P. (2024). Hybrid heuristic for solving the Euclidean travelling salesman problem. *SN Computer Science*, 5, Article 1050. <https://doi.org/10.1007/s42979-024-03417-9>
- [12] Jaballah, R., Coelho, L. C., & Renaud, J. (2025). Time-dependent routing and road network precision. *Operations Research Forum*, 6, Article 65. <https://doi.org/10.1007/s43069-025-00467-4>
- [13] Kádár, B., & Ribeiro Martins, M. (2026). The contribution of accessible social media data to the work of tourism research communities: A bibliometric network analysis of studies using Flickr data. *Information Technology & Tourism*, 28, Article 40. <https://doi.org/10.1007/s40558-026-00380-4>
- [14] Lee, H., & Kang, Y. (2021). Mining tourists' destinations and preferences through LSTM-based text classification and spatial clustering using Flickr data. *Spatial Information Research*, 29(6), 825–839. <https://doi.org/10.1007/s41324-021-00397-3>
- [15] Lin, X., Teng, X., Shen, Z., & Mao, Q. (2026). Understanding how destination attributes shape tourist visitation on cultural routes through social media data and interpretable machine learning. *npj Heritage Science*. <https://doi.org/10.1186/s40494-026-02427-5>
- [16] Wikimedia Foundation. (2025). *Wikimedia Analytics pageviews API: Per-article, all-access, user agent* [Data set].
- [17] Nevşehir Provincial Directorate of Culture and Tourism. (2025). *Official visitor statistics for Cappadocia museums and archaeological sites, 2024–2025* [Data set].
- [18] Güngör, S., Sucu, F., Dinç, Y., Çetin, M., & Adıgüzel, A. D. (2025). GIS based daily tourism route proposal for surrounding provinces and districts from Ankara's Çankaya district (Turkey). *Environment, Development and Sustainability*, 27, 26713–26738. <https://doi.org/10.1007/s10668-024-04800-5>
- [19] Zhao, J., He, J., Yi, J., Ran, X., & Li, J. (2026). GIS-based geotourism route design in Changbaishan Global Geopark. *Geoheritage*, 18, Article 75. <https://doi.org/10.1007/s12371-026-01298-3>
- [20] Kızılkın, Y., Birinci, S., Camcı, A., & Çakır, Ç. (2026). Analysis of sustainable development priorities in geopark areas: The case of Türkiye. *Geoheritage*, 18, Article 64. <https://doi.org/10.1007/s12371-026-01286-7>
- [21] Noorian, A. (2024). A personalized context and sequence aware point of interest recommendation. *Multimedia Tools and Applications*, 83, 77565–77594. <https://doi.org/10.1007/s11042-024-18522-3>
- [22] Yan, W., Wang, X., & Lu, Y. (2025). Deep learning based personalized tourism recommendation for behavior analysis and route optimization. *Scientific Reports*. <https://doi.org/10.1038/s41598-025-22592-0>
- [23] Rocha, Á., Abreu, A., de Carvalho, J. V., Liberato, D., Alén González, E., & Liberato, P. (Eds.). (2020). *Advances in tourism, technology and smart systems* (Smart Innovation, Systems and Technologies, Vol. 171). Springer. <https://doi.org/10.1007/978-981-15-2024-2>
- [24] Divsalar, G., Divsalar, A., Jabbarzadeh, A., & Sahebi, H. (2022). An optimization approach for green tourist trip design. *Soft Computing*, 26, 4303–4332. <https://doi.org/10.1007/s00500-022-06834-1>
- [25] Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, Environment and Urban Systems*, 65, 126–139. <https://doi.org/10.1016/j.compenurbsys.2017.05.004>
- [26] Vansteenwegen, P., Souffriau, W., Vanden Berghe, G., & Van Oudheusden, D. (2009). Iterated local search for the team orienteering problem with time windows. *Computers & Operations Research*, 36(12), 3281–3290. <https://doi.org/10.1016/j.cor.2009.03.008>

Appendix A. Per-POI time windows and service times

Time windows and service times are modelling assumptions based on representative public operating schedules for each attraction type (Table 1); special temporal rules (sunrise-only balloon, afternoon-closing underground cities, evening sunset viewpoints) are applied as described in Section 2.6. The complete per-POI assignment used in all experiments is given in Table A1.

Table A1. Time windows, service times and special rules for every point of interest.

POI	Type	Window	Service (min)	Special rule
Acıgöl	Water body	06:00–20:00	30	—
Asmalı Konak	Mansion	08:00–18:00	30	—
Avanos Saç Müzesi	Museum	08:00–18:00	45	—
Avanos Vadisi	Valley	06:00–20:00	90	—
Aziz Basil Şapeli	Church	08:00–18:00	20	—
Aşıklar Vadisi	Valley	06:00–20:00	90	Sunset-preferred
Balkan Deresi	Valley	06:00–20:00	90	—
Vadisi				
Balon Turu	Balloon	05:30–07:30	120	First activity
(Göreme)				(sunrise)
Balımlı Sultan	Tomb	08:00–18:00	25	—
Türbesi				
Belha	Monastery	08:00–18:00	30	—
Manastırı(Özkonak;)				
Damat İbrahim	Complex	08:00–18:00	30	—
Paşa Külliyesi				



Damsa Barajı ve Gölü	Water body	06:00–20:00	30	—
Derinkuyu	Underground city	08:00–17:00	60	—
Devrent Vadisi(Hayal Vadisi)	Valley	06:00–20:00	90	Sunset-preferred
El Nazar Kilisesi	Church	08:00–18:00	20	—
Elmalı Kilisesi	Church	08:00–18:00	20	—
Fırkatan Kilisesi	Church	08:00–18:00	20	—
Gomeda Vadisi	Valley	06:00–20:00	90	—
Göreme	Town centre	06:00–22:00	60	—
Göreme Açık Hava Müzesi	Open-air museum	08:00–18:00	120	—
Göreme Roma Kalesi ve Mezarı	Castle	08:00–19:00	45	—
Güllüdere Kilisesi(Çavuşin)	Church	08:00–18:00	20	—
Gülşehir	Town centre	06:00–22:00	60	—
Günay Müze	Museum	08:00–18:00	45	—
Güvercinlik Vadisi	Valley	06:00–20:00	90	—
Hacı Bektaş Veli Türbesi	Tomb	08:00–18:00	25	—
Hacıbektaş	Town centre	06:00–22:00	60	—
Hacıbektaş Atatürk Evi Müzesi	Museum	08:00–18:00	45	—
Ihlara Vadisi	Valley	06:00–20:00	90	—
İshak Kalesi	Castle	08:00–19:00	45	—
Kapadokya Kültür Merkez	Culture centre	09:00–18:00	45	—
Kapadokya Sanat ve Tarihi Müzesi(B)	Museum	08:00–18:00	45	—
Kapadokya Yaşayan Miras Müzesi	Museum	08:00–18:00	45	—
Karanlık Kilise	Church	08:00–18:00	20	—
Kaymaklı	Underground city	08:00–17:00	60	—
Kozaklı	Town centre	06:00–22:00	60	—
Kızlar Manastırı(Rahibeler)	Monastery	08:00–18:00	30	—
Kızılçukur Vadisi	Valley	06:00–20:00	90	Sunset-preferred
Manastırlar Vadisi	Monastery	08:00–18:00	30	—
Mazi Yeraltı Şehri	Underground city	08:00–17:00	60	—
Mehmet Şahir Paşa Medresesi	Complex	08:00–18:00	30	—
Meskendir Vadisi	Valley	06:00–20:00	90	—
Nevşehir Kalesi	Castle	08:00–19:00	45	—
Nevşehir Müzesi	Museum	08:00–18:00	45	—
Ortahisar	Town centre	06:00–22:00	60	—
Pancarlık Vadisi	Valley	06:00–20:00	90	—
Peribacaları	Viewpoint	06:00–20:00	45	—
Saklı Kilise	Church	08:00–18:00	20	—
Saruhan (Avanos)	Caravanserai	08:00–18:00	30	—
Sarıca Kilisesi	Church	08:00–18:00	20	—
Tatların	Underground city	08:00–17:00	60	—
Taşkın Paşa Camii	Mosque	08:00–18:00	25	—
Temenni Tepesi	Viewpoint	06:00–20:00	45	—
Tokalı Kilisesi	Church	08:00–18:00	20	—
Uçhisar Kalesi	Castle	08:00–19:00	45	Sunset-preferred
Vaftizci Yahya Kilisesi(Çavuşin)	Church	08:00–18:00	20	—
Yılanlı Kilise(Kalesi)	Church	08:00–18:00	20	—
Zelve Kiliseleri	Church	08:00–18:00	20	—
Zemi Vadisi	Valley	06:00–20:00	90	—
Çavuşin	Town centre	06:00–22:00	60	—
Ürgüp Kadıkalesi	Castle	08:00–19:00	45	—
Ürgüp Kiliseleri	Church	08:00–18:00	20	—
Ürgüp Müzesi	Museum	08:00–18:00	45	—
Üzengi Vadisi	Valley	06:00–20:00	90	—
Üzümlü Kilise	Church	08:00–18:00	20	—
Üç Güzeller	Viewpoint	06:00–20:00	45	Sunset-preferred