Re-Sequencing the Formula 1 Calendar to Reduce Carbon Emissions and Transport Costs: A Time-Dependent Travelling Salesman Model with Climate and Ramadan Constraints

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***Abstract*—Background. Logistics and business travel account for about three-quarters of the carbon footprint that Formula 1 reports for its 24-race season. Both depend on the order in which the Grands Prix are held, yet the calendar is set through commercial negotiation, and the effect of its sequence on emissions has not been quantified with a model calibrated to the sport's own data. Methods. We formulate calendar sequencing as a time-dependent travelling salesman problem. The race dates of the official 2026 calendar are kept fixed, and the 24 venues are assigned to them. A layered network-flow mixed-integer program minimises the emissions of air freight, road freight and personnel air travel. It applies separate itinerary rules for European road freight, for flyaway events and for gaps of more than a week between races. The constraints are climate windows derived from NASA POWER temperature climatologies, the Ramadan exclusion that Formula 1 applies to Gulf venues, and optionally a fixed season opener in Melbourne and finale in Abu Dhabi. Distances come from great-circle geometry with the UK government's 8% uplift for flights and from OpenStreetMap road routing. Emission factors are the UK government's 2025 conversion factors. Freight tonnage and the number of travelers is calibrated so that the model reproduces the logistics and travel emissions Formula 1 reported for 2024. Costs combine 2025 fuel prices with the 2025 EU carbon price.**

Results. Calibration implies 958 t of freight and 4,070 travelers moved per leg. Without recalibration, the model reproduces Formula 1's restated 2018 logistics emissions to within 0.5%. The official 2026 calendar generates 135.8 kt CO_2e of transport emissions. With the opener and finale fixed and each venue's monthly mean temperature allowed to change by at most 4 °C, the optimal sequence emits 117.3 kt, a 13.6% (18.4 kt) reduction. Air-freight tonne-kilometres fall by 24.9%, and fuel and carbon costs fall by US$5.67 million a year. Reordering races within their current months alone saves 4.7%, and moving eight races to a new month captures 12.3%. Without the climate and anchor constraints the saving reaches 26.0%. All results are robust to radiative forcing, road-freight tonnage, team locations and the calibration year. Each instance solves to proven optimality in seconds to a few minutes. Conclusions. The 2026 calendar already improves on 2024, but a large share of the sport's controllable transport emissions still depends on race order. Most of the saving needs only modest changes in season and few moves between months. The model gives rights holders and promoters a transparent way to price such changes during calendar negotiations.

***Index Terms*—sports scheduling; Formula 1; time-dependent travelling salesman problem; mixed-integer programming; carbon emissions; event logistics; sustainable transport**

I. INTRODUCTION

The FIA Formula One World Championship is a touring business. Each season the cars, garages, spare parts, broadcast equipment and hospitality structures of eleven teams and the commercial rights holder are carried to venues on five continents, together with several thousand engineers, mechanics, officials and media staff. Formula 1 itself reports that, in 2024, the movement of this equipment (*logistics*) emitted 70,341 t CO_2e and the movement of people (*travel*) a further 71,068 t, before credit is taken for sustainable aviation fuel certificates (Formula 1, 2025b). Together they make up 74.9% of the sport's reported footprint of 188,732 t; the cars' power units account for less than one per cent (Formula 1, 2019, 2025b). Formula 1 has committed to net zero by 2030, defined as a reduction of

at least 50% from a re-stated 2018 baseline of 228,793 t CO_2e, with the remainder offset (Formula 1, 2025b). With factory energy already largely renewable, the remaining reductions must come mainly from transport.

The order of the races is the one transport decision that costs the sport nothing in equipment. Formula 1 has begun to use it. In 2024 the Japanese Grand Prix was moved from September to April to sit with the Asia–Pacific races, Azerbaijan was paired with Singapore, and Qatar was placed before nearby Abu Dhabi. For 2026, the Canadian Grand Prix was moved to May and Monaco to June so that the European races form a single block, which removes one transatlantic crossing for freight (Formula 1, 2025b). These changes were negotiated one at a time. Neither the sport nor the academic literature has published an optimisation model that measures how far the current calendar is from the lowest-emission order that respects the sport's real constraints, or what each constraint costs.

The question is harder than a textbook travelling salesman problem for four reasons. First, the dates are not free. A calendar has a fixed number of weekends, back-to-back and triple-header blocks, and a summer shutdown, so the problem is to assign venues to dated slots. Second, the cost of travelling between two venues depends on the slot. When races are on consecutive weekends, freight and personnel move directly. When there is a gap, people fly home to the team bases, which are mostly in England, and European trucks return to the factories. A leg therefore costs a different amount depending on where in the season it falls, which makes the problem a *time-dependent* travelling salesman problem (Picard and Queyranne, 1978; Gouveia and Voß, 1995). Third, many venues can only host in certain months, because of heat in the Gulf, cold in Canada and the Australian season. In 2026 the Muslim-majority Gulf hosts also could not race during Ramadan, which ran through February and March (Formula 1, 2025a). Fourth, the opener in Melbourne and the finale in Abu Dhabi are commercially fixed in practice.

This paper builds such a model and applies it to the official 2026 calendar of 24 rounds. It answers three research questions:

RQ1. By how much could transport emissions and costs fall if the same 24 Grands Prix were held on the same 24 dates in a different order, while respecting climate, religious and contractual constraints?

RQ2. How does the attainable reduction depend on how far venues may move from their current climate conditions and on how many venues may change month?

RQ3. Which parts of the reduction come from freight and which from personnel travel, and how robust is the result to the main modelling choices?

The paper makes four contributions. First, it formulates calendar sequencing as a slot-assignment, time-dependent travelling salesman problem. The formulation is a layered network flow, which CBC solves to proven optimality in seconds to a few minutes. Second, it builds the leg costs from public, sourced inputs: OpenStreetMap road routing, government emission factors, NASA climate data, and fuel and carbon prices. It calibrates freight tonnage and the number of travellers to Formula 1's own reported 2024 emissions and validates the calibration on the 2018 season. Third, it traces two policy frontiers, emissions against climate tolerance and emissions against the number of races that change month. These frontiers show negotiators what each concession is worth. Fourth, it applies the model to the calendar as it actually unfolded in 2026, when the Bahrain and Saudi Arabian races were cancelled and Bahrain's race was relocated to Malaysia, and shows that the conclusions hold.

Section 2 reviews the literature. Section 3 describes the data and the calibration. Section 4 presents the model. Section 5 reports the results, Section 6 discusses their implications and limitations, and Section 7 concludes.

II. LITERATURE REVIEW

This study draws on four strands of work: the carbon footprint of sport and of Formula 1 in particular; operational research on sports scheduling; travelling salesman and routing models that account for time and emissions; and the small number of studies that have proposed alternative Formula 1 calendars.

2.1. The carbon footprint of sport and of Formula 1

Sport is both a contributor to and a casualty of climate change. Orr and Inoue (2019) set out a framework for the climate vulnerability of sport organisations, and McCullough et al. (2020) define *sport ecology* as the study of the relationship between sport and the natural environment within sport management. Much of the

empirical work concerns spectator travel. Collins et al. (2009) compare ecological-footprint and input–output methods for assessing mega-events. Dolf and Teehan (2015) show that travel dominates the emissions of a university's varsity sports programme and evaluate options for reducing them. Wicker (2019) estimates the travel footprint of active sport participants in Germany, and Loewen and Wicker (2021) estimate that of football fans travelling to Bundesliga matches. At the scale of tourism as a whole, Lenzen et al. (2018) estimate that tourism produced about 8% of global greenhouse-gas emissions, with air transport the largest single component. A recurring finding is that the location and order of events, not on-site operations, determine most of the footprint.

Formula 1 has published its footprint since 2019. Its first sustainability strategy reported 256,551 t CO_2e for 2018, with logistics at 45%, business travel at 27.7%, factories and facilities at 19.3%, event operations at 7.3% and power units at 0.7% (Formula 1, 2019). The 2025 update re-stated the 2018 baseline at 228,793 t to reflect better supplier data. It reported a 2024 footprint of 188,732 t (168,720 t after sustainable aviation fuel certificates), a 26% reduction from the baseline (Formula 1, 2025b). Academic studies of Formula 1 have examined its alignment with the Sustainable Development Goals (Öztopcu, 2023) and its communication strategies, including the charge of greenwashing (Sturm et al., 2024). Al-rubaye and Naimi (2025) forecast the FIA's emissions to 2030. Nandurkar and Grady (2026) build a system-dynamics model calibrated to Formula 1's reported data and find that calendar regionalisation is the second most effective lever after sustainable aviation fuel. Their model, however, represents regionalisation as an aggregate percentage reduction rather than deriving it from an explicit sequence of venues.

2.2. Operational research in sports scheduling

Sports scheduling is a mature field of operational research. Kendall et al. (2010) provide an annotated bibliography of the field, Rasmussen and Trick (2008) review round-robin scheduling, and Van Bulck et al. (2020) propose a classification and data format for round-robin timetabling problems. The problem closest in spirit to ours is the *travelling tournament problem* of Easton et al. (2001), in which teams play a double round robin and the objective is to minimise total travel distance subject to limits on consecutive home and away games. Applications include European football leagues (Goossens and Spieksma, 2012), the Brazilian national championship (Ribeiro and Urrutia, 2012) and the South American qualifiers for the FIFA World Cup, where integer programming reduced travel and balanced rest (Durán et al., 2017). These problems schedule pairings among many teams. A motor-racing championship differs: the whole travelling circus moves as one from venue to venue, so the problem becomes a single route through dated slots.

2.3. Travelling salesman, time dependence and green routing

The travelling salesman problem has been a test bed for integer programming since Dantzig et al. (1954). Its many formulations for the asymmetric case are compared by Öncan et al. (2009). When the cost of an arc depends on its position in the tour, the problem becomes the time-dependent travelling salesman problem introduced by Picard and Queyranne (1978). Gouveia and Voß (1995) classify its formulations and show that layered network-flow models give strong linear-programming relaxations. Dumas et al. (1995) solve the travelling salesman problem with time windows by dynamic programming. Our model has both features: arc costs depend on the gap between consecutive slots, and each venue may be visited only in climatically acceptable windows. Routing with explicit emission objectives was popularised by the pollution-routing problem of Bektaş and Laporte (2011). Multi-objective trade-offs of the kind we trace are usually generated with the ε-constraint method (Mavrotas, 2009).

2.4. Proposed Formula 1 calendars

Only a few studies have proposed optimised Formula 1 calendars, and none appears in a peer-reviewed operational research outlet. Nagle (2023), writing for an economics consultancy, groups 23 venues into seven geographical hubs and solves a travelling salesman problem over them.

He reports a 37.3% reduction in distance compared with 2019. Vajirkar and Lee (2024), in a student preprint, order the calendar with a branch-and-bound procedure and a nearest-neighbour rule, using air transport between continents and road transport within Europe. Both studies minimise distance rather than emissions. Neither calibrates to Formula 1's reported footprint,

models personnel travel, or keeps the real race dates, gaps and summer break. Both treat climate and contracts loosely or not at all.

2.5. Positioning of this study

Table 1 summarises the most relevant studies. This paper fills the gap between the aggregate scenario model of Nandurkar and Grady (2026) and the distance-only sequencing exercises of Nagle (2023) and Vajirkar and Lee (2024).

It solves an exact time-dependent sequencing model on the official race dates. It converts distance into emissions with mode-specific government factors, calibrated so that the totals match Formula 1's reported data, and into costs with observed fuel and carbon prices.

It also reports how the attainable reduction depends on climate tolerance, contractual anchors and the number of races that change month.

Table 1. Representative studies and the decision each address.

Study	Setting	Method	Scope of emissions
Easton et al. (2001)	Round-robin leagues	Integer programming (TTP)	Distance only
Durán et al. (2017)	FIFA qualifiers	Integer programming	Distance and rest
Bektas and Laporte (2011)	Vehicle routing	MILP, fuel-based emissions	Road freight
Formula 1 (2025b)	Formula 1, 2018–2024	Carbon accounting	All scopes, reported
Nandurkar and Grady (2026)	Formula 1, to 2030	System dynamics, Monte Carlo	Aggregate levers
Nagle (2023)	Formula 1, 23 venues	TSP over regional hubs	Distance only
Vajirkar and Lee (2024)	Formula 1	Branch and bound, nearest neighbour	Distance \(\times \) constants
This study	Formula 1, 2026 dates	Time-dependent TSP, layered MILP, frontiers	Freight and travel, calibrated; fuel and carbon cost

III. DATA AND CALIBRATION

Every input to the model comes from a published source and is listed in Table 2. Where a modelling rule has to be chosen, such as the itinerary followed when there is a gap between races, the alternatives are tested in Section 5.6.

3.1. Calendars

The primary case is the official 2026 calendar announced by Formula 1 and the FIA, with 24 rounds from Melbourne on 8 March to Abu Dhabi on 6 December (Formula 1, 2025a). It includes Madrid's debut on 13 September and keeps Bahrain and Saudi Arabia in April because Ramadan fell in February and March (Formula 1, 2025a). The calendar was later disrupted. Both April races were cancelled on 14 March 2026 because of the regional conflict (Cleeren, 2026), and the Bahrain Grand Prix was relocated to the Sepang circuit in Malaysia on 4 October, restoring a 23-race season (Reuters, 2026). We analyse this revised calendar separately in Section 5.5. The 2024 calendar (24 rounds) is used for calibration and the 2018 calendar (21 rounds) for validation. The model keeps each calendar's dates exactly as published, including the summer break and the pattern of back-to-back weekends. Only the assignment of venues to dates is a decision.

3.2. Venues, team bases and distances

The 29 venues that appear in at least one of these calendars were geolocated at the circuit. The equipment and most of the travelling staff start from the teams' factories. Of the eleven teams on the 2026 grid, eight race from bases in England, two from Italy and one from Switzerland.

The 2018 and 2024 grids of ten teams had seven, two and one respectively. Each itinerary through a base is weighted by these counts, using London Heathrow, Bologna and Zurich airports for flights and the factory regions for road freight.

Flight distances are great-circle distances increased by 8%, the uplift the UK government prescribes for routing and stacking (DESNZ, 2025). Road distances between the 12 European venues and the three bases (105 pairs) were computed with the Open Source Routing Machine on OpenStreetMap data (Luxen and Vetter, 2011).

3.3. Emission factors

Emissions are computed with the UK government's 2025 greenhouse-gas conversion factors (DESNZ, 2025), which Formula 1 itself uses alongside supplier data (Formula 1, 2025b). Freight flights emit 0.5313 kg CO_2e per tonne-kilometre on international and long-haul routes and 0.75539 kg on short-haul routes under 3,700 km. Articulated heavy goods vehicles at average load emit 0.07800 kg per tonne-kilometre. Personnel flights emit 0.0842 kg per passenger-kilometre on international routes and 0.07559 kg on short-haul routes. These are the factors without the radiative-forcing multiplier. The factors with it, which account for non-CO_2 effects at altitude (Lee et al., 2021), are used as a sensitivity case.

3.4. Calibration of freight tonnage and travelling staff

The tonnage of freight and the number of people Formula 1 moves are not published in a form that can be attached to individual legs. We therefore calibrate two scale parameters. The first is the effective freight payload T carried on every leg. The second is the effective number of travellers P. They are chosen so that the model reproduces the 2024 logistics (70,341 t) and travel (71,068 t) emissions in Formula 1's emissions table (Formula 1, 2025b). These figures exclude the credit for sustainable aviation fuel certificates, so they reflect physical activity. Calibration gives T = 958 t and P = 4,070 people.

The calibration was validated on 2018, a season with a different calendar, different venues and a different number of rounds. With the 2024 values of T and P, the model predicts 2018 logistics emissions of 67,671 t, against Formula 1's re-stated figure of 67,994 t, an error of 0.5%. Calibrating directly to 2018 would give T = 963 t. The freight side of the model therefore transfers across seasons. For travel the model predicts 63,778 t against a reported 79,425 t. The shortfall of 19.7% matches the 25% reduction in travel emissions that Formula 1 attributes to remote broadcast operations introduced after 2018 (Formula 1, 2025b). In other words, fewer people travelled in 2024 than in 2018. This is a change in P, not an error in the itinerary model.

3.5. Costs

Transport costs are measured at 2025 prices. Fuel burned is derived from emissions using the government's combustion factors: 2.54269 kg CO_2e per litre of aviation turbine fuel and 2.57082 kg per litre of diesel (DESNZ, 2025). Jet fuel is priced at IATA's 2025 average of US$90 per barrel (IATA, 2025). Diesel is priced at the 2025 EU average before taxes of EUR 0.7623 per litre, computed from the European Commission's Weekly Oil Bulletin (European Commission, 2026). Carbon is priced at the 2025 average EU Emissions Trading System allowance price of EUR 74.35 per tonne (ICAP, 2026). Euro amounts are converted at the European Central Bank's 2025 average of US$1.12998 per euro (European Central Bank, 2026). One tonne of CO_2e from aviation therefore implies US$222.6 of fuel, one tonne from road haulage US$335.1, and every tonne US$84.0 of carbon cost. As a fuller measure for air transport, we also scale fuel cost by IATA's 2025 estimate that fuel makes up 26.8% of airline operating costs (IATA, 2025).

3.6. Climate windows and Ramadan

Formula 1 schedules races where and when conditions are acceptable to drivers, spectators and broadcast-ers. To make this constraint explicit and reproducible, we use the NASA POWER monthly climatology of 2-metre air temperature for 2001–2020 at each circuit, which is derived from the MERRA-2 reanalysis (Gelaro et al., 2017; NASA Langley Research Center, 2026).

Two rules follow from it. The first is an *envelope*. A venue may host in a month only if its mean temperature in that month lies within the range observed across all races actually held in 2024 and 2026, which is 5.55–29.77 °C. The range runs from Suzuka in March to Jeddah in April, so no venue is sent to conditions colder or hotter than the sport has recently accepted.

The second is a *tolerance* Δ. A venue's mean temperature in its new month may differ from that in its current month by at most Δ °C. Low values of Δ keep each event close to its current season, and $\Delta = \infty$ applies the envelope alone. We take Δ = 4 °C as the reference setting and report the full range. Finally, the four Gulf venues (Bahrain, Saudi Arabia, Qatar and Abu Dhabi) and Malaysia may not host a race whose weekend overlaps Ramadan, 18 February to 19 March 2026, in line with Formula 1's stated practice (Formula 1, 2025a).

IV. MATHEMATICAL MODEL

4.1. Itinerary rules

Movements between consecutive rounds follow the operating pattern Formula 1 describes (Formula 1, 2025b). Freight for the European rounds travels by truck, and freight for flyaway rounds travels by chartered aircraft. Let E be the set of venues in road-connected Europe, which includes Great Britain via the Channel crossing. For a leg from venue i to venue j with a gap of g days between the races:

1. *Europe to Europe*: freight travels by road directly when $g \leq 7$ (a back-to-back weekend). Otherwise, the trucks return to the bases and set out again.
2. *Europe to flyaway* and *flyaway to Europe*: freight is trucked between the venue and the bases and flown between the bases and the flyaway venue.
3. *Flyaway to flyaway*: freight is flown directly.
4. *Personnel*: staff fly directly when $g \leq 7$. Otherwise, they fly home to their base and out again.
5. The season begins with a move from the bases to the first venue and ends with a return from the last venue.

Table 2. Model inputs and sources.

Parameter	Value	Source
Race dates ij	2026 official (24), 2026 revised (23), 2024 (24), 2018 (21)	Formula 1 (2025a); Reuters (2026); Cleeren (2026)
Venue and base locations	29 circuits; England (8 teams), Italy (2), Switzerland (1)	Circuit and team locations
Flight distance	Great circle × 1.08	DESNZ (2025)
Road distance	OSRM driving distance, 105 pairs	Luxen and Vetter (2011)
Freight flight factor	0.5313 (long), 0.75539 (short) kg/t-km; with RF 0.89939, 1.27835	DESNZ (2025)
HGV factor	0.07800 kg/t-km (articulated, average laden)	DESNZ (2025)
Passenger flight factor	0.0842 (long), 0.07559 (short) kg/p-km; with RF 0.14253, 0.12786	DESNZ (2025)
Short-/long-haul boundary	3,700 km	DESNZ (2025)
Calibration targets	Logistics 70,341 t; travel 71,068 t (2024, without SAFc)	Formula 1 (2025b)
Validation targets	Logistics 67,994 t; travel 79,425 t (2018 re-stated)	Formula 1 (2025b)
Fuel combustion factors	Jet 2.54269, diesel 2.57082 kg/litre	DESNZ (2025)
Jet fuel price	US$90/barrel (2025 average)	IATA (2025)
Fuel share of airline cost	26.8% (2025)	IATA (2025)
Diesel price	EUR 0.7623/litre before taxes (2025 average)	European Commission (2026)
Carbon price	EUR 74.35/t (2025 average EUA)	ICAP (2026)
Exchange rate	US$1.12998/EUR (2025 average)	European Central Bank (2026)
Climate	Monthly mean 2-m temperature, 2001–2020	NASA Langley Research Center (2026)
Ramadan 2026	18 February – 19 March	Formula 1 (2025a)

Each leg involving a base is the weighted average over the three base countries. These rules give, for every ordered pair (i, j) and gap g, a freight emission per tonne $e^F_{ij}(g)$ and a travel emission per person $e^P(g)$.

The emission of the leg is

$$c_{ij}(g) = Te^F_{ij}(g) + Pe^P_{ij}(g), \quad (1)$$

with analogous costs c_{0i} for the opening move and c_{i0} for the closing move.

4.2. Notation

Sets and parameters.

- N: venues on the calendar, $|N| = n$; $S = \{1,\ldots,n\}$: race slots with dates $d_1 < \cdots < d_n$.
- $g_s = d_{s+1} - d_s$: gap in days after slot s; $m(s)$: calendar month of slot s.
- $F \subseteq N \times S$: feasible venue–slot pairs (climate envelope, tolerance Δ, Ramadan, anchors).
- m_i: month in which venue i is held in the official calendar; K: maximum number of venues allowed to change month.

Decision variables. $x_{is} \in \{0,1\}$ equals 1 if venue i is held in slot s; $y_{ijs} \geq 0$ is the flow on the arc from venue i in slot s to venue j in slot $s+1$.

4.3. Formulation

$$\min \quad Z = \sum_{i \in N} c_{0i} x_{i1} + \sum_{s=1}^{n-1} \sum_{i \in N} \sum_{j \neq i} c_{ij}(g_s) y_{ijs} + \sum_{i \in N} c_{i0} x_{in} \tag{2}$$

$$\text{s.t.} \quad \sum_{s \in S} x_{is} = 1 \quad \forall i \in N \tag{3}$$

$$\sum_{i \in N} x_{is} = 1 \quad \forall s \in S \tag{4}$$

$$\sum_{j \neq i} y_{ijs} = x_{is}, \quad \sum_{j \neq i} y_{jis} = x_{i,s+1} \quad \forall i \in N, s < n \tag{5}$$

$$x_{is} = 0 \quad \forall (i,s) \notin F \tag{6}$$

$$\sum_{i \in N} \left(1 - \sum_{s : m(s) = m_i} x_{is} \right) \leq K \tag{7}$$

$$x_{is} \in \{0,1\}, \quad y_{ijs} \geq 0$$

Constraints (3)– (4) assign each venue to exactly one slot and each slot to exactly one venue. Con-straints (5) link consecutive slots through a layered network, so that one unit of flow passes through the venue chosen in each slot. Constraint (6) removes infeasible pairs, which are dropped from the model rather than fixed at zero. Constraint (7), used only for the disruption frontier, limits the number of venues held in a different month from the official calendar. The opener and finale anchors are imposed through F by allowing only Melbourne in slot 1 and only Abu Dhabi in slot n.

Proposition 1. *For any binary x satisfying* (3)–(4)*, the flow constraints* (5) *have a unique solution, which is $y_{ijs} = x_{is} x_{j,s+1}$. This solution is binary, and the objective* (2) *then equals the exact emission of the sequence defined by x.*

Proof. Fix s. By (4) exactly one venue i^* has $x_{i^*s} = 1$ and exactly one venue j^* has $x_{j^*,s+1} = 1$, and $i^* \neq j^*$ by (3). The first set of equations in (5) forces $y_{ijs} = 0$ for every $i \neq i^*$. The second forces $y_{ijs} = 0$ for every $j \neq j^*$. The remaining arc must then carry $y_{i^* j^* s} = 1$. Summing $c_{ij}(g_s)\, y_{ijs}$ over all slots gives the cost of the legs actually travelled.

Proposition 1 means that integrality needs to be imposed only on the n^2 assignment variables. The layered flow is the time-dependent formulation recommended by Gouveia and Voß (1995). Because each leg cost depends on the slot through g_s, it captures the itinerary rules exactly, which a standard asymmetric travelling salesman formulation (Öncan et al., 2009) cannot do. The objective can be switched from emissions to cost by replacing $c_{ij}(g)$ with fuel plus carbon cost. Because emissions and fuel are proportional within each mode, the two objectives differ only through the mix of road and air.

4.4. Solution method and experiments

The model was implemented in Python with PuLP (Mitchell et al., 2011) and solved with the open-source CBC solver (Forrest and Lougee-Heimer, 2005) to a relative optimality gap of 0.01%. With the reference settings it has 220 binary and 1,988 continuous variables and 486 constraints, and without climate limits 466 binary and 8,396 continuous variables.

The experiments are as follows.

1. Evaluation of the 2018, 2024, official 2026 and revised 2026 calendars.
2. Climate tolerance: optimisation for $\Delta \in \{2,3,4,5,6,8,\infty\}$ °C, with and without the opener and finale anchors.
3. Disruption frontier: optimisation with $K = 0,2,...,24$ at $\Delta = 4$ °C and $\Delta = \infty$, using the ε-constraint method (Mavrotas, 2009).
4. Cost objective: optimisation of fuel plus carbon cost at the reference settings.
5. Revised calendar: optimisation of the 23 venues of the revised 2026 calendar on its own dates.
6. Sensitivity: radiative forcing, road-freight tonnage three times the calibrated payload, direct travel for gaps of up to 14 days, all teams based in England, and calibration to 2018. In each case T and P are recalibrated before optimising.

V. RESULTS

All emissions are in tonnes of CO_2e (kt = 1,000 t). All costs are in 2025 US dollars.

5.1. Emissions of the published calendars

Figure 1 decomposes the transport emissions of the four published calendars. The 2024 calendar emitted 141.4 kt, which matches the calibration targets by

construction. The official 2026 calendar reduces this to 135.8 kt (4.0% lower) with the same number of races. This is consistent with Formula 1's stated aim of removing a transatlantic crossing by moving Canada to May (Formula 1, 2025b).

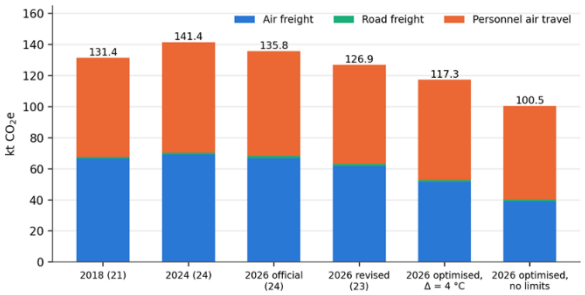

Figure 1. Transport emissions by component for the published calendars and two optimised 2026 sequences (number of rounds in brackets). The 2024 values equal Formula 1's reported logistics and travel emissions by construction.

Air freight accounts for 66.9 kt of the 2026 total, personnel travel for 67.6 kt and road freight for only 1.2 kt. Air freight moves 122.7 million tonne-kilometres and personnel cover 811 million passenger-kilometres. At 2025 prices the official calendar's transport costs US$30.36 million in fuel and US$11.41 million in carbon, a total of US$41.77 million. On the fuller air-operating-cost measure it costs US$111.8 million.

5.2. The optimal sequence for 2026

Table 3 compares the official calendar with two optimal sequences on the same 24 dates. Both keep Melbourne first and Abu Dhabi last. The first is the reference setting ($\Delta = 4\,^{\circ}C$), and the second applies the climate envelope alone. Figure 2 maps the official calendar and the reference sequence.

Table 3. Official 2026 calendar and optimal sequences on the same dates (Melbourne first, Abu Dhabi last).

Round	Date	Gap (days)	Official 2026	Optimal, $\Delta = 4\,^{\circ}C$	Optimal, envelope only
1	8 Mar	7	Australia	Australia	Australia
2	15 Mar	14	China	Singapore	Singapore
3	29 Mar	14	Japan	Qatar	Azerbaijan
4	12 Apr	7	Bahrain	Bahrain	Qatar
5	19 Apr	14	Saudi Arabia	Saudi Arabia	Bahrain
6	3 May	21	Miami	Italy (Monza)	Belgium
7	24 May	14	Canada	Monaco	Netherlands
8	7 Jun	7	Monaco	Hungary	Austria
9	14 Jun	14	Barcelona	Austria	Hungary
10	28 Jun	7	Austria	Madrid	Monaco
11	5 Jul	14	Britain	Barcelona	Italy (Monza)
12	19 Jul	7	Belgium	Netherlands	Madrid
13	26 Jul	28	Hungary	Belgium	Barcelona
14	23 Aug	14	Netherlands	Britain	Britain
15	6 Sep	7	Italy (Monza)	Azerbaijan	China
16	13 Sep	13	Madrid	Brazil	Japan
17	26 Sep	15	Azerbaijan	Canada	Las Vegas
18	11 Oct	14	Singapore	Miami	Canada
19	25 Oct	7	United States	United States	Mexico
20	1 Nov	7	Mexico	Mexico	United States
21	8 Nov	13	Brazil	Las Vegas	Miami
22	21 Nov	8	Las Vegas	Japan	Brazil
23	29 Nov	7	Qatar	China	Saudi Arabia
24	6 Dec	–	Abu Dhabi	Abu Dhabi	Abu Dhabi
Transport emissions (kt CO_2e)			135.8	117.3	110.9
Reduction			–	13.6%	18.3%
Fuel and carbon cost (US$ million)			41.77	36.10	34.12
Venues changing month			–	14	18

The reference sequence emits 117.3 kt, which is 18.4 kt (13.6%) less than the official calendar. The structure of the solution is intuitive once the itinerary rules are taken into account. After Melbourne, the season goes to Singapore and the Gulf, and Qatar, Bahrain and Saudi Arabia are paired in March and April after Ramadan.

It then runs one European block from Monza in May to Silverstone in late August. The road legs between European venues are short and largely back-to-back, while the long-haul flights out of and back to Europe happen only once. From September the season moves east to Baku and then makes a single westward loop through the Americas: Brazil, Montreal, Miami, Austin, Mexico City and Las Vegas. It then crosses the Pacific to Suzuka and Shanghai in November and finishes in Abu Dhabi.

The official calendar, by contrast, flies from Japan to the Gulf and then to Miami in the spring, and in the autumn travels from Europe to Baku, Singapore, the Americas and back to the Gulf.

The saving comes mainly from freight. Air-freight emissions fall from 66.9 kt to 51.6 kt (22.8%), and air-freight tonne-kilometres from 122.7 million to 92.2 million (24.9%). Personnel emissions fall by a smaller 4.5%, from 67.6 kt to 64.6 kt.

The difference arises because staff fly home during every gap of more than a week, wherever the calendar goes, whereas flyaway freight goes directly from one venue to the next. Fuel and carbon costs fall from US$41.77 million to US$36.10 million, a saving of US$5.67 million a year (US$4.12 million of fuel and US$1.55 million of carbon). On the fuller air-operating-cost measure the saving is US$15.2 million. Optimising cost instead of emissions returns exactly the same sequence (Section 5.6). Because the saving reduces cost as well as emissions, the abatement has a negative cost per tonne.

The climate implications of the reference sequence are modest by construction. The largest changes are Japan and China moving from March to November (3.8 and 3.9 ◦C), Miami from May to October (0.6 ◦C warmer), and Brazil from November to September (1.8 ◦C cooler). Canada moves from May to late September, which is 3.7 ◦C warmer on average. Fourteen venues change month, and ten stay where they are.

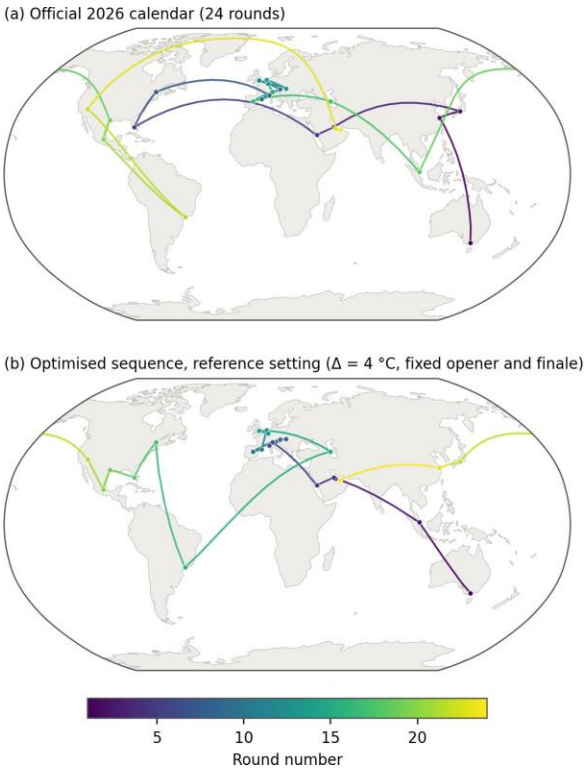

Figure 2. Season routes of (a) the official 2026 calendar and (b) the optimal sequence at the reference setting, coloured by round. Flights are drawn as great circles.

5.3. The value of climate flexibility

Figure 3 and Table 4 show how the attainable reduction grows as the climate tolerance Δ is relaxed. With both anchors kept, even Δ = 2 ◦C, which allows only small shifts of season, reduces emissions by 9.4%. The reduction reaches 13.6% at 4 ◦C, 16.1% at 6 ◦C and 18.3% when only the envelope applies. Releasing the commercial anchors adds a further 1.4 to 7.7 percentage points, depending on Δ.

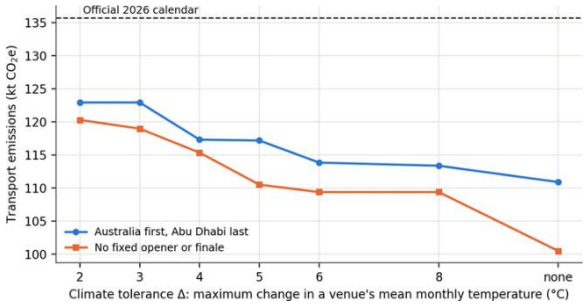

Figure 3. Minimum transport emissions as a function of the climate tolerance Δ, with and without a fixed opener (Melbourne) and finale (Abu Dhabi). The dashed line is the official 2026 calendar.

With neither anchors nor tolerance, the minimum is 100.5 kt, 26.0% below the official calendar. That sequence begins in Spain in March and ends in Monaco in December, and so ignores the opener and finale contracts and puts Monaco in December. It shows the scale of the opportunity rather than a practical calendar.

Table 4. Optimal sequences by climate tolerance (kt CO_2e; reduction relative to the official 2026 calendar, 135.8 kt).

	Melbourne first, Abu Dhabi last				No fixed opener or finale		
Δ (°C)	Emissions	Reduction	Moves	Cost (US$m)	Emissions	Reduction	Moves
2	122.9	9.4%	9	37.83	120.3	11.4%	9
3	122.9	9.4%	11	37.83	119.0	12.4%	12
4	117.3	13.6%	14	36.10	115.4	15.0%	14
5	117.2	13.7%	15	36.06	110.5	18.6%	15
6	113.9	16.1%	17	35.03	109.4	19.4%	21
8	113.4	16.5%	15	34.88	109.4	19.4%	21
Envelope only	110.9	18.3%	18	34.12	100.5	26.0%	23

5.4. The disruption frontier

Promoters plan ticketing, hotel capacity and local events years ahead, so each venue that changes month carries a real negotiating cost. Figure 4 traces the minimum emissions when at most K venues may leave their current month. With $K = 0$, every race stays in its month and only the order within months changes, for example by holding Japan before China and Barcelona before Monaco. This alone saves 6.3 kt (4.7%).

Allowing four moves raises the saving to 9.3% and eight moves to 12.3%. At the reference tolerance the frontier is flat beyond twelve moves, where the full 13.6% is reached. Without a tolerance limit, eight moves capture 16.9% of the 18.3% available. The frontier is concave, so the first concessions are the most valuable: on average each of the first four moves is worth about 1.6 kt a year, against about 0.4 kt for each move between the eighth and the twelfth.

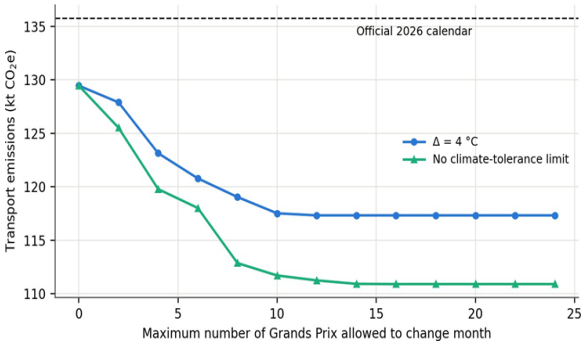

Figure 4. Disruption frontier: minimum transport emissions when at most K Grands Prix may be held in a different month from the official 2026 calendar (Melbourne first, Abu Dhabi last).

5.5. The revised 2026 calendar

The calendar that was actually run in 2026 had 23 races. Bahrain and Saudi Arabia were removed from April and Bahrain's race was held at Sepang on 4 October (Cleeren, 2026; Reuters, 2026). The model estimates its transport emissions at 126.9 kt. They are lower than the official calendar's mainly because two Gulf flyaways disappeared, not because the order improved. Re-optimising the 23 venues on the revised dates reduces emissions to 116.9 kt (7.9%) at the reference setting and to 108.2 kt (14.7%) with the envelope alone. The pattern is the same: a single European block, one loop through the Americas, and an Asian swing before the Gulf finale. The smaller percentage saving reflects the fact that the revision already removed two poorly placed flyaways.

5.6. Sensitivity analysis

Table 5 repeats the reference optimisation under alternative assumptions, recalibrating T and P in each case so that the 2024 targets are still met. The reduction is almost unchanged when radiative-forcing factors are used (13.6%), when road freight is assumed to weigh three times the calibrated payload (13.4%), when every team is based in England (13.3%), and when the model is calibrated to 2018 instead of 2024 (12.6%). The one assumption that matters is the itinerary rule for personnel and trucks. If staff and road freight travel directly whenever two races are at most 14 days apart, so that fewer people return home, the reduction doubles to 26.0%. The reason is that more of the calendar's legs then depend on race order. The

reference rule is therefore conservative. The cost-minimising sequence is identical to the emission-minimising one, because air transport dominates both objectives.

Table 5. Sensitivity of the reference result (Δ = 4 °C, anchors kept). *T* and *P* are recalibrated in each case.

Case	*T* (t)	*P*	Official (kt)	Optimal (kt)	Reduction
Reference	958	4,070	135.8	117.3	13.6%
Radiative-forcing factors	570	2,405	135.7	117.2	13.6%
Road-freight tonnage × 3	929	4,070	136.1	117.9	13.4%
Direct travel for gaps ≤ 14 days	958	5,192	136.3	100.9	26.0%
All teams based in England	961	4,058	136.0	118.0	13.3%
Calibrated to the 2018 season	963	5,069	152.7	133.4	12.6%
Cost objective (fuel + carbon)	958	4,070	135.8	117.3	13.6%

5.7. Computational performance

At the reference setting, the integer program solves to proven optimality in 2.1 seconds. The hardest instance, with no anchors and Δ = 8 °C, took 201 seconds. The linear-programming relaxation is within 2.4% of the integer optimum at the reference setting and within 7.8% with the envelope alone, as expected of a layered time-dependent formulation (Gouveia and Voß, 1995). Every frontier point solved in under two minutes. The model is therefore fast enough to be used interactively during calendar negotiations, re-solving whenever a promoter proposes a new date or a venue drops out.

VI. DISCUSSION

6.1. Implications for Formula 1 and its promoters

Race order is a significant lever. The 18.4 kt saving at the reference setting equals 9.8% of the sport's entire 2024 footprint before sustainable aviation fuel credits. That is nearly half of the 40.1 kt reduction, before sustainable aviation fuel credits, that Formula 1 achieved between 2018 and 2024 with renewable factory energy, more efficient aircraft and remote broadcasting (Formula 1, 2025b). It needs no new technology, and it reduces cost rather than adding to it. The 2026 changes to Canada and Monaco show that the sport accepts such reasoning. The model quantifies how much remains available.

Small concessions capture most of the value. The concave disruption frontier means negotiators need not redraw the whole calendar. Ordering races differently within their current months is worth 4.7%, and eight changes of month capture nine-tenths of what is available at the reference tolerance. The most valuable moves are clear. The Asian races (Japan, China and Singapore) should be grouped either in spring or in autumn, not split between them. The Gulf events should form one block. The Americas should be visited in one loop rather than in three separate trips from Europe and Asia.

Personnel travel is set by gaps, not just by order. Personnel emissions, which are about half the transport footprint, respond much less to race order (4.5%) than freight does (22.8%). This is because staff go home whenever there is a gap of more than a week. The sensitivity case with direct travel for gaps of up to 14 days shows that combining a better order with a calendar that keeps staff on the road between nearby flyaways roughly doubles the saving. The obvious trade-off is staff welfare, because longer flyaway blocks keep people away from home for longer. The model can price this trade-off but cannot settle it.

Climate tolerance is a policy choice. The tolerance Δ makes explicit a constraint that is usually left implicit. A rights holder that accepts a 6 °C shift for a few venues gains 2.5 percentage points over the reference setting. One that also accepts a different opener or finale gains more. With climate change shifting the comfortable season at several venues (Orr and Inoue, 2019), the climate windows themselves will need periodic updating, which the data source allows.

6.2. Relation to previous work

The results are consistent with, but more conservative than, earlier distance-based estimates. Nagle (2023) reports a 37.3% reduction in distance, but his model

does not use fixed dates, the Ramadan constraint, the commercial anchors or the return of staff and trucks to base. These rules account for the difference between his figure and our 13.6–26.0% range. The system-dynamics model of Nandurkar and Grady (2026) treats calendar regionalisation as a lever worth up to 41% at its maximum. The present model gives an operational basis for choosing a value for that lever. Methodologically, the problem sits between the travelling tournament problem (Easton et al., 2001) and the time-dependent travelling salesman problem (Picard and Queyranne, 1978). The layered formulation (Gouveia and Voß, 1995) proves an effective way to capture itinerary rules that depend on the gap between races.

6.3. Limitations

- *Calibrated scale.* Freight tonnage and the number of travellers is calibrated rather than observed. The calibration transfers across seasons for freight (0.5% error on 2018), but per-leg tonnages and sea-freight kits, which Formula 1 rotates between flyaway events, are not modelled. Sea freight is absorbed into the calibrated payload.
- *Uniform payload.* The same payload is assumed on every leg and in every mode. The sensitivity on road tonnage shows that the result does not depend on this.
- *Climate proxy.* Monthly mean temperature is a proxy for suitability. Rain, humidity, daylight and typhoon or hurricane seasons are not modelled, and the 0.5° climatology grid smooths local conditions.
- *Commercial constraints.* Hosting fees, broadcast time zones, clashes with other major events and the promoters' own calendars are not represented beyond the two anchors and the disruption limit.
- *Fans and event operations.* Spectator travel lies outside Formula 1's reporting boundary and is not modelled, and event operations do not depend on race order.

VII. CONCLUSION

This paper formulated the sequencing of the Formula 1 calendar as a time-dependent travelling salesman problem on fixed race dates. Leg costs reflect the itineraries actually used for freight and staff. The model was calibrated to the sport's reported emissions, validated on an earlier season and solved exactly with free software. Applied to the official 2026 calendar, it shows that the same 24 races on the same dates could be held in an order that emits 13.6% less transport CO_2e and costs US$5.67 million less in fuel and carbon each year. The order keeps Melbourne first and Abu Dhabi last, avoids Ramadan in the Gulf and limits each venue's temperature change to 4 °C. Most of the saving needs only a few venues to change month. With fewer constraints the reduction reaches 26%, and the conclusions hold for the revised 23-race season that was actually run.

Several extensions would strengthen the analysis. Per-leg freight manifests, including the sea-freight kits, would replace the calibrated payload. A second objective for staff welfare, such as limits on consecutive weekends away from home, would bring personnel considerations into the optimisation. Uncertainty in race cancellations, of the kind experienced in 2026, could be handled by robust or stochastic optimisation. Projected climate data would allow climate windows to be set for the 2030s. The same approach applies directly to other touring championships, such as MotoGP, the World Endurance Championship and Formula E.

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