Tacoma Narrows SUP—Deterministic Crossing Windows

An applied, safety-conservative method for forecasting stand-up paddleboard crossing opportunities across the Tacoma Narrows

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Abstract

We present a deterministic, safety-conservative method to forecast daylight windows for stand-up paddleboard (SUP) crossings between the Gig Harbor Lighthouse and Point Defiance, spanning the north mouth of the Tacoma Narrows. The method fuses NOAA tide and current predictions with route-aligned interpolation and slack-centered window fitting to produce actionable daily guidance constrained by user-defined safety thresholds, fixed transit speed, and operational buffers. Example constraints include maximum cross current ≤ 1.5 kt, beach interval, and safety time. The system is implemented as two Airtable automations: (1) payload assembly for sun, tide, current, route, and metadata, and (2) deterministic window calculation for route-level gating, slack clustering, exact-fit scheduling, headline generation, and text-to-speech output. We document the model assumptions, algorithmic steps, data schema, and operational safeguards, and we discuss validation against trusted visual tools and local domain knowledge. The approach intentionally favors false negatives over false positives to reduce safety risk.

1 Introduction

Crossing the Tacoma Narrows by SUP is constrained by spatially nonuniform tidal currents, tight daylight, and the need to return safely across the same waterway. While rich numerical forecasts exist, translating them into simple, reliable "go/no-go" windows for human use demands a deterministic, auditable pipeline that (i) models the cross-channel variation of flow, (ii) centers activity near slack, and (iii) enforces hard safety caps.

This work formalizes that pipeline into a reproducible daily product: a single JSON record per run date, plus an accompanying human-readable marine forecast line, that the Author can operationalize.

Contributions. We provide:

1. A route-aware, slack-centered window construction that fits the entire out-and-back plus beach and safety buffers within a current cap.
2. A multi-station gating strategy across mid-channel and west-side current stations, merged into a single opportunity per slack phase when the full union satisfies constraints.

3. A practical Airtable-native implementation with quota-aware batching, versioned schema, and deterministic outputs suitable for text-to-speech and publishing.

2 Background and Setting

Geography. The Narrows "elbow" aligns roughly 140°/320° in its northern reach and 030°/210° south of the elbow. The crossing route is near-orthogonal to the north mouth of the Narrows and is therefore maximally sensitive to cross-current.

Flow directions. In this locale, flood currents flow north to south; ebb currents flow south to north. Station signs encode direction. For gating, we use magnitudes and reserve signs for phase and slack detection.

Route and stations.

- Route endpoints: Gig Harbor Lighthouse $(47.326746, -122.572665)$ and Point Defiance $(47.317670, -122.547817)$. Great-circle distance is operationally fixed at 2.6 nm.
- Stations with latitude, longitude, and depth: PUG1524, mid-channel, $(47.3060, -122.5500)$, 40 ft; PUG1526, west channel, $(47.3040, -122.5567)$, 42 ft; and PUG1523, Gig Harbor Entrance, $(47.3242, -122.5719)$, 11 ft.

Operational assumptions.

- SUP speed $v_{\text{sup}} = 3.0$ kt.
- Round-trip transit time $t_{\text{transit}} = \left(\frac{2.6}{3.0}\right) 60 \approx 52$ min.
- Beach interval $t_{\text{beach}} = 15$ min and safety buffer $t_{\text{safety}} = 15$ min.
- Required trip minutes $t_{\text{req}} = t_{\text{transit}} + t_{\text{beach}} + t_{\text{safety}} = 82$ min.
- Daylight bounds come from sun ephemeris; windows must be fully within daylight.

3 Problem Definition

Given tide predictions at multiple nearby stations, current predictions at PUG1524, PUG1526, and PUG1523 as time-stamped slack, ebb, and flood events, a fixed route between Lighthouse and Point Defiance, safety constraints such as maximum allowable cross current $c_{\max}$, and fixed timing parameters $(t_{\text{transit}}, t_{\text{beach}}, t_{\text{safety}})$, the goal is to produce zero or more daylight windows of exact length t_{req}, centered around clustered slack, such that the route-level current magnitude never exceeds $c_{\max}$ across the entire out-and-back.

Let $I_j(t)$ be the scalar speed in knots at station $j \in \{\text{PUG1524}, \text{PUG1526}, \text{PUG1523}\}$ after interpolation to minute resolution. At each minute t, define the route-level gate as

$$G(t) = \max_{j \in \mathcal{J}} I_j(t), \tag{1}$$

where $\mathcal{J}$ is the set of stations used for safety gating. A candidate window $[T, T + t_{\text{req}}]$ is admissible if and only if

$$\max_{t \in [T, T+t_{\text{req}}]} G(t) \le c_{\max}, \tag{2}$$

the center of this window is within a slack cluster, and the full interval lies within daylight. This definition enforces that both directions of the crossing, Gig Harbor to Point Defiance and Point Defiance to Gig Harbor, remain under cap because $G(t)$ is evaluated minute-by-minute across the full interval.

4 Data and Sources

- **NOAA Tides & Currents**: official harmonic predictions for tide heights and tidal currents, including slack, flood, and ebb magnitudes.
- **XTide harmonics**: David Flater's data set, widely used for harmonic predictions.
- **DeepZoom**: a qualitative visual validation and plausibility-check tool.
- **Local geography and seamanship input**: the Author's domain insights on safe practice and site specifics.

We treat NOAA predictions as ground truth for this purpose and reconcile station-phase signs as described in Section 2.

5 Methodology

5.1 Time series interpolation and slack clustering

Event normalization. For each station, we parse events into a monotonically increasing series of tuples $(t_i, v_i, \text{phase}_i)$, where $v_i \ge 0$ is the magnitude in knots and $\text{phase}_i \in \{\text{F}, \text{E}, \text{SL}\}$.

Piecewise linear interpolation. We construct a minute-resolution magnitude $I_j(t)$ by linear interpolation between events, skipping piecewise artifacts at exact slacks and using the nearest non-slack segments to determine threshold crossings.

Slack clustering. Because slacks arrive at slightly different times across stations, we compute a clustered slack center $t_\star$ by grouping slacks within a window, for example 30 min, across PUG1524, PUG1526, and PUG1523 and taking the median time. Windows are then centered on $t_\star$.

5.2 Route-level gating

We adopt a conservative max-over-stations gate, with optional inverse-distance-weighted route sampling if needed:

$$G(t) = \max\{I_{\mathrm{PUG1524}}(t), I_{\mathrm{PUG1526}}(t), I_{\mathrm{PUG1523}}(t)\}. \tag{3}$$

This reflects the operational fact that a paddler must cross both west-side and mid-channel flows; treating them as separate opportunities is unsafe. In alternative configurations, we can evaluate $I(t)$ along 5–9 points on the straight Gig Harbor to Point Defiance line via inverse-distance weighting from station positions, then set $G(t) = \max_s I_s(t)$. Results have been consistent with the simpler max-of-stations guard in our site.

5.3 Window construction: slack-centered exact fit

We compute the exact runtime:

$$t_{\mathrm{req}} = t_{\mathrm{transit}} + t_{\mathrm{beach}} + t_{\mathrm{safety}}. \tag{4}$$

For each clustered slack $t_\star$ occurring within daylight, we propose

$$[T_{\mathrm{start}}, T_{\mathrm{end}}] = \left[t_\star - \frac{t_{\mathrm{req}}}{2}, t_\star + \frac{t_{\mathrm{req}}}{2}\right]. \tag{5}$$

We accept the window if $G(t) \leq c_{\max}$ for all minutes in $[T_{\mathrm{start}}, T_{\mathrm{end}}]$ and $[T_{\mathrm{start}}, T_{\mathrm{end}}]$ lies within daylight. The paddle-by time equals the window start: the latest safe time to leave the Lighthouse to complete the round trip with all buffers.

5.4 Merging across stations

If multiple station-anchored proposals around the same slack cluster produce overlapping intervals, we take the union only if the union interval also satisfies the gate everywhere, with no minute exceeding $c_{\max}$. Otherwise, we keep the intersection or the single most conservative member. This prevents the earlier error mode where mid-channel and west-side windows appeared as separate opportunities.

5.5 Safety policy

- **Conservative cap**: recommend $c_{\max} = 1.5$ kt by default. Raising the cap widens windows but increases risk.
- **Hard daylight constraint**: no twilight creep; the full window must be inside sunrise–sunset.
- **Exact fit**: enforcing fixed 82 min windows avoids overly wide on-paper gates and guarantees return under similar conditions.

6 Implementation in Airtable

6.1 Automation 1: payload assembly

Automation 1 reads `sun_ephemeris`, `tide_predictions`, `master_currents`, and `config_params`. It builds one payload per day with `run_date`, `sun`, `config`, `route`, `stations_meta`, `tides`, and `currents`. It batches N days ahead, for example 7, each run; skips existing future records to avoid quota burn; and writes to `payloads` with `status = ready`, stored in view `Ready`.

6.2 Automation 2: deterministic crossing calculator

Automation 2 pulls the earliest ready payload from the Ready view, or processes a small batch, computes windows as described in Section 5, and writes a single JSON blob to `gpt_inputs.crossing_json` with `status = received`. It also generates compact `forecast_text` suitable for text-to-speech.

Quota-aware design. The implementation uses minimal table queries, a single read of the Ready batch, and a single upsert per output day.

7 Validation and Quality Assurance

- **Sanity constraints**: block windows where any station exceeds $c_{\max}$ at any minute; require exact 82-minute duration; enforce daylight.
- **Slack alignment**: center windows on clustered slack, computed as the median of PUG1523, PUG1524, and PUG1526 slacks within roughly 30 min.
- **Local knowledge checks**: compare against expected morning windows near high slack and afternoon windows near low slack; apply conservative closures when strong ebb or flood currents bracket slack tightly.
- **Cross-tool plausibility**: check qualitative agreement with DeepZoom visuals on August 13–14 scenarios; when discrepancies appear, favor safety by preferring false negatives.

Example: 2025-08-14. Output window 09:35–10:57 centered at 10:16, with $\max G(t) \approx 0.92$ kt $\leq$ 1.5, fully daylight. Pass.

8 Limitations and Future Work

- **Station coverage**: three stations are proximate but not continuous over the route; inverse-distance-weighted sampling mitigates this but cannot capture small eddies or shear layers.

- **Harmonic prediction errors**: extremes and meteorological forcing, including pressure and wind, can shift actual slack timing or magnitude.
- **No wind or sea-state gating yet**: adding wind thresholds and chop or sea-state proxies would improve practical safety.
- **Adaptive caps**: dynamic $c_{\max}$ by rider skill or cargo could be supported.
- **Learning residuals**: a post-hoc bias corrector could align predictions to observed drifter data without changing the deterministic core.

9 Results Snapshot: Illustrative

2025-08-14.

- Window 1: 09:35–10:57, paddle-by 09:35, centered on high-slack 10:16, $\max G(t) \approx 0.92$ kt, daylight OK.
- No PM window in this example: strong ebb envelops low-slack; merged union fails cap, so the method emits no false opportunity.

User-facing forecast example.

> Marine forecast for Thursday, August 14. Daylight today runs from 6:05 a.m. to 8:24 p.m. There is 1 safe opportunity to cross the Narrows between Gig Harbor Lighthouse and Point Defiance. Window 1 runs 09:35 to 10:57, based on mid-channel currents. Slack is near high tide at 10:16. Do not paddle away from the lighthouse later than 9:35 a.m.

10 Related Work and References

1. NOAA Tides & Currents: tide and tidal current predictions based on harmonic constituents.
2. XTide Harmonics: David Flater's annual harmonic data releases used widely in prediction software.
3. DeepZoom: visual current and tide explorer for Puget Sound; used here for qualitative validation. Contributors include Jay Borseth, Morgan Conrad for wind data wrangling, and Chris Mulverhill for Coast Pilot processing.

Specific station IDs and data tables are integrated into the Airtable base and mirrored in the payload schema.

11 Conclusion

We introduced a deterministic, conservative pipeline that translates tide and current predictions into actionable SUP crossing windows for the Tacoma Narrows. By centering crossings on clustered slack, gating the entire round trip at a strict current cap, and merging station proposals only when the union remains safe, the system avoids two classic failure modes: (i) overly wide, misleading safe windows and (ii) fragmented station-specific opportunities that do not represent true route risk. The result is a reproducible, auditable daily product suitable for public guidance and text-to-speech while remaining fast and quota-efficient inside Airtable.

A Airtable Schema: High Level

- `sun_ephemeris`: `date_local`, `sunrise_local`, `sunset_local`, `day_length`.
- `tide_predictions`: `Station_ID`, `Date`, `Time`, `Pred_Ft`, `High_Low`.
- `master_currents`: `date_time`, `event` (SL/F/E), `speed_knots`, `station_id`.
- `config_params`: `param`, `value`, typed at load.
- `payloads`: `run_date`, `payload_json`, `status` with single-select values ready or processed.
- `gpt_inputs`: `run_date`, `crossing_json`, `status` with single-select value received.

Automation 1 writes `payloads` in the Ready view. Automation 2 reads Ready and writes `gpt_inputs`.

B Payload and Output Key Fields

- **Payload**: `run_date`, `sun`, `config`, including `max_current_allowed_kt` and `safety_buffer_min`, `route`, `stations_meta`, `tides` for 944-series stations, and `currents` for PUG-series stations.
- **Output**: `windows[]` with `start_local`, `end_local`, `center_slack_local`, `paddle_by_local`, `max_cross_current_kt`, and `anchor_station`; plus `headline`, `tide_summary`, `forecast_text`, `assertions`, and `config_snapshot`.

C Algorithm Pseudocode: Sketch

```
for each run_date payload:
    build minute-resolution I_j(t) for j in {PUG1524, PUG1526, PUG1523}
    find station slacks; cluster within slack_cluster_min to get centers t*
    for each t* within daylight:
        T0 = t* - t_req / 2
        T1 = t* + t_req / 2
```

```
        if [T0, T1] is within daylight and
           max_t in [T0, T1] max_j I_j(t) <= c_max:
            add proposal window [T0, T1]
    merge proposals that belong to the same slack cluster:
        use union only if all minutes in union satisfy max_j I_j(t) <= c_max
    emit merged windows with paddle_by = start of each window
```

D Acknowledgements

The Author provided site knowledge, safety constraints, and quality assurance; GPT-5 designed and implemented the deterministic method and Airtable automations. We thank NOAA for public predictions and DeepZoom for an excellent comparative visualization tool.

E License

F Safety, Risk, and Legal Disclaimer

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Operational limitations. The approach intentionally favors false negatives, omitting a potentially acceptable crossing, over false positives, suggesting a crossing that is unsafe. Models and scripts cannot capture all local effects, including micro-eddies, shear layers, wind jets, wakes, debris, or rapidly evolving weather.

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