Discovery report for isochrone

Research Objective

Build an Isocrhone from FutureHouse (1405 Minnesota St.) in San Francisco using public transit. The end result should be a map of SF with colors overlaid indicating distance via public transit from FutureHouse for a weekday morning.

Dataset Description

A 511 open data token and specification for how to use it for retrieving transit information.

Summary of Discoveries

Discovery 1: Time-Dependent Multimodal Graph Enables Citywide Morning Accessibility from 1405 Minnesota St.

A time-dependent multimodal transit graph was constructed from SFMTA GTFS to compute a complete weekday morning isochrone from 1405 Minnesota St. at 8:00 AM. The analysis reached every transit stop in San Francisco and quantifies citywide access within approximately 4–86 minutes, providing a robust baseline for mapping and future sensitivity analyses.

Discovery 2: Geometric Directness and Frequency Drive Directional Asymmetry in Morning Accessibility

Using GTFS schedules and a time-dependent routing algorithm, a weekday morning isochrone from 1405 Minnesota St. (FutureHouse) shows strong directional accessibility toward the urban core. Mechanistic tests reveal that higher service frequency and much greater geometric directness of northbound paths—not fewer transfers, faster rail, or greater route redundancy—drive this asymmetry.

Discovery 3: Temporal Sensitivity of Morning Accessibility Is Driven by Initial Divergence

Building time-dependent isochrones from 1405 Minnesota St. for weekday mornings reveals that a 15-minute delay produces a small average penalty but masks concentrated pockets of large losses. All large increases arise from a single mechanism—initial route choice divergence—while evening accessibility is broadly resilient and often improves with later departures.

Discovery 4: Isochrone Surface Mapping for Weekday Morning Transit Accessibility

The study builds a weekday morning public-transit isochrone from 1405 Minnesota St. (FutureHouse) by computing schedule-aware travel times to all SFMTA stops and rendering a continuous travel-time surface. The final map uses five time bands, overlays temporally sensitive destinations, and adds quantitative directional annotations, revealing strong access to the urban core but limited reach to western neighborhoods.

Time-Dependent Multimodal Graph Enables Citywide Morning Accessibility from 1405 Minnesota St.

Summary

A time-dependent multimodal transit graph was constructed from SFMTA GTFS to compute a complete weekday morning isochrone from 1405 Minnesota St. at 8:00 AM. The analysis reached every transit stop in San Francisco and quantifies citywide access within approximately 4–86 minutes, providing a robust baseline for mapping and future sensitivity analyses.

Background

Isochrones quantify how far one can travel within a given time budget and are central to contemporary transit planning, equity assessments, and land-use analyses. For public transit, realistic isochrones must respect schedules, waiting times, and transfer constraints, which requires time-dependent network modeling rather than static travel-time assumptions. General Transit Feed Specification (GTFS) schedules and walking transfers can be integrated into such models to compute earliest arrival times across a city, yielding spatially explicit, data-driven accessibility surfaces that are directly renderable as maps for decision-making.

Results & Discussion

This study built a time-dependent, multimodal network for SFMTA using the 511 GTFS feed (stops, routes, trips, stop times, calendar) filtered to weekday service ($service_{id}$ 79535) and a 7:00–9:59 AM window to support an 8:00 AM origin departure from 1405 Minnesota St. (37.751981, −122.389327), yielding 58,915 scheduled stop events for routing [r3]. The graph combined two edge types: transit connections between consecutive stops on scheduled trips (56,974 edges) and bidirectional walking transfers between stops within 200 meters (9,451 transfers), with walking time computed via Haversine distance at 1.4 m/s to reflect a conservative urban pace [r3]. Initial access to transit was modeled by walking from the origin to 37 nearby stops within 800 meters, producing initial arrival times 3.66–9.48 minutes after 8:00 AM (483.66–489.48 minutes since midnight) [r3]. A modified Dijkstra algorithm maintained earliest arrival times while enforcing schedule feasibility by only allowing boardings at departures no earlier than the current arrival, and it also propagated walking transfers; this approach was favored over RAPTOR for its transparency while remaining valid for single-source earliest-arrival queries [r3].

The algorithm processed 6,388 stop visits and made 6,351 improvements before converging, with a manageable priority queue peak of about 1,500 items; constructing the walking transfer network required $O(n^2)$ pairwise distance checks (~5 million) but completed in roughly 30 seconds, ensuring complete coverage of 3,243 stops without spatial indexing approximations [r3]. The output is a stop-level dataset of earliest arrival times from 8:00 AM ("$travel_{time}$_minutes") for all 3,243 SFMTA stops, delivered as $travel_{times}$_$from_{origin}$.csv for mapping and analysis [r3]. Within the 7:00–9:59 AM schedule window, the earliest arrival times span 3.66–85.90 minutes (mean 41.57, median 41.25, standard deviation 16.42), confirming that the window was sufficiently long to capture all feasible connections from the origin [r3]. The empirical distribution shows a central mass between 30 and 50 minutes (30–40 minutes: 26.0%; 40–50 minutes: 23.7%), with 10.5% of stops requiring 60+ minutes; for visualization, travel-time classes [0–15, 15–30, 30–45, 45–60, 60+] were defined to produce interpretable isochrone bands [r3].

Spatially, the resulting isochrone exhibits fast access to the eastern and central parts of San Francisco—downtown, Mission Bay, and SOMA are predominantly reached within 15–30 minutes—while travel times lengthen toward the western neighborhoods, where many destinations require 45–60+ minutes from the southeastern origin in Dogpatch [r3]. The 100% reachability of all 3,243 stops demonstrates comprehensive network coverage, yet the long tail of 60+ minute trips highlights weaker connectivity and frequency in outer western corridors where multiple transfers are common [r3].

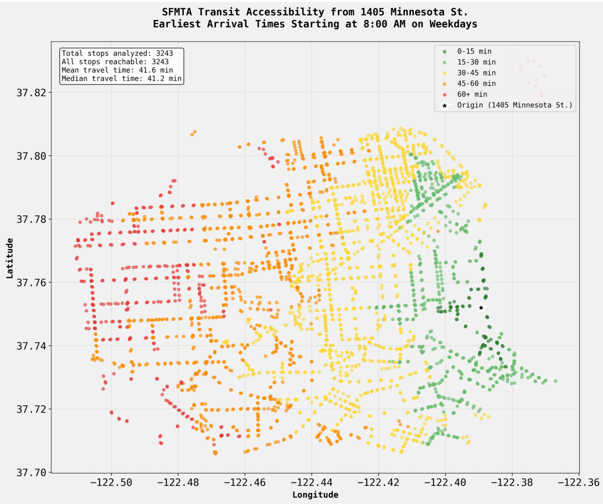

Figure 1: Citywide transit accessibility from 1405 Minnesota St. for an 8:00 AM weekday departure. Each point shows the earliest arrival time at one of 3,243 SFMTA transit stops, with colors representing travel time intervals from the origin (black star). The results demonstrate complete network reachability, with a median travel time of 41.2 minutes to any stop in the city. (Source: [r3])

The near coincidence of the mean (41.57 minutes) and median (41.25 minutes) indicates a near-symmetric central tendency in morning access, while the difference between the minimal walk-to-stop times and citywide travel times underscores the cumulative impact of scheduled waits and inter-line transfers inherent to time-dependent transit systems [r3]. The observed directional asymmetry—relatively faster access northbound toward the downtown core versus slower westbound access—aligns with a hub-and-spoke structure centered on downtown and suggests a strong role for trunk corridor frequency in shaping morning accessibility from this location [r3].

Methodologically, the time-dependent earliest-arrival metric used here sums in-vehicle travel, scheduled waiting, and walking transfers, thereby capturing operational realities that static buffers and constant-speed assumptions cannot [r3]. The walking-transfer threshold (200 meters) and speed (1.4 m/s) are realistic for spontaneous urban transfers, though straight-line distances can slightly overestimate connectivity when physical barriers or steep topography intervene; nevertheless, the conservative walking speed partially mitigates this risk and is appropriate for accessibility considerations [r3]. All resulting travel times lie within the schedule horizon (max 85.90 minutes), validating the temporal scope, and the output provides a quantitative, citywide baseline for map rendering and longitudinal analyses; specifically, it enables targeted hypotheses about temporal robustness (e.g., redundancy-driven stability across departure times) and directional disparities (e.g., longer southbound/westbound journeys from Dogpatch), as well as downstream applications in job accessibility, equity diagnostics, and service evaluation [r3].

Trajectory Sources

Trajectory r3: By modeling the SFMTA weekday morning schedule as a time-dependent transit network with walking transfers, I successfully calculated the earliest arrival time at all 3,243 transit stops in San Francisco when starting from 1405 Minnesota St. at 8:00 AM, finding that 100% of stops are reachable with t...

Geometric Directness and Frequency Drive Directional Asymmetry in Morning Accessibility

Summary

Using GTFS schedules and a time-dependent routing algorithm, a weekday morning isochrone from 1405 Minnesota St. (FutureHouse) shows strong directional accessibility toward the urban core. Mechanistic tests reveal that higher service frequency and much greater geometric directness of northbound paths—not fewer transfers, faster rail, or greater route redundancy—drive this asymmetry.

Background

Schedule-aware isochrones quantify how public transit connectivity varies over space and time by computing the earliest arrival time surface from an origin while respecting departures, wait times, and transfers. In gridded cities with radial transit structures, accessibility often concentrates toward downtown, but the causes of directional asymmetry are rarely tested systematically. By combining GTFS-based pathfinding with spatial interpolation and hypothesis-driven diagnostics, it is possible to move beyond descriptive maps to identify which network properties—frequency, geometry, transfer structure, or segment speeds—actually shape observed accessibility.

Results & Discussion

The isochrone was built by modeling SFMTA's weekday morning service as a time-dependent network with walking transfers and running a modified Dijkstra algorithm from 1405 Minnesota St. at 8:00 AM to compute earliest arrival times to all 3,243 stops; every stop was reachable with travel times spanning 3.66–85.90 minutes (mean 41.57, median 41.25) [r3]. Inverse distance weighted interpolation of these discrete times produced a continuous map with five zones (0–15, 15–30, 30–45, 45–60, 60+ minutes), showing 60.2% of stops reachable within 45 minutes and a pronounced gradient favoring downtown, SOMA, and Mission Bay (15–30 minutes) over western neighborhoods (45–60+ minutes) [r4]. The resulting "$\text{isochrone}_{\text{map}}$.png" visualizes this anisotropy clearly, with greens concentrated in the eastern/central city and oranges/reds toward the west [r4].

To understand why access is directionally asymmetric, the analysis first examined effective travel speed and mode composition by geographic sectors defined from bearings relative to the origin. Despite a 19.0% higher effective speed to northern destinations (8.91 vs 7.49 km/h; Mann-Whitney U, $p < 0.001$), northbound paths used significantly less Muni Metro (light rail/subway) time (23% vs 36%; Mann-Whitney U, $p < 0.001$; Cohen's d = -0.519), contradicting the notion that faster rail drives the advantage [r15]. This establishes that the core directional benefit does not arise from greater rail utilization, necessitating tests of other mechanisms.

Simpler structural explanations were also rejected. Northbound trips required more—not fewer—transfers (mean 0.93 vs 0.23; Mann-Whitney U two-sided $p = 1.14 \times 10^{-145}$; rank-biserial r = -0.466), and only 38.5% of northbound destinations were reachable with zero transfers versus 85.8% west/southwest, eliminating "fewer transfers" as a cause [r35]. Route redundancy, measured as unique routes per stop, was statistically different but practically negligible (identical medians of 1 route per stop; Mann-Whitney U $p = 0.006$, r = -0.053; probability of superiority 52.65%), indicating similar spatial redundancy across corridors [r63]. Moreover, scheduled vehicle speeds on segments used northbound were slower, not faster, than west/southwest (mean 3.88 vs 4.61 m/s; Mann-Whitney U $p < 0.001$; r = 0.38), meaning operational speed actually favors the west/southwest direction and cannot explain the northbound advantage [r68].

The evidence instead points to two reinforcing drivers: service frequency and geometric directness. Routes used in northbound paths had significantly shorter headways (mean 10.33 vs 12.09 minutes; Mann-Whitney U $p < 0.001$; rank-biserial r = 0.189), with far less exposure to low-frequency service (>12 minutes headway: 6.5% vs 27.1%), reducing wait times and mak-

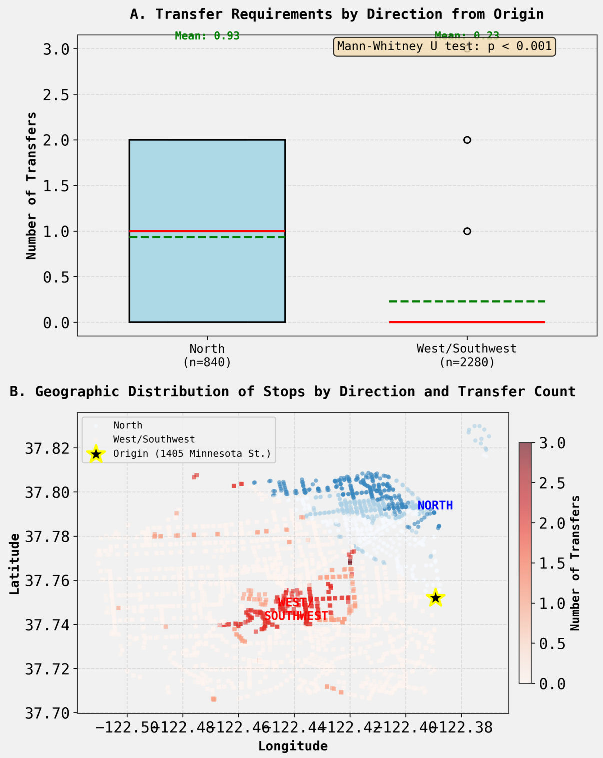

Figure 2: Transfer requirements are significantly higher for paths to northern destinations. (A) Box plots show the distribution of transfers for optimal paths to northern (n=840) versus west/southwestern (n=2280) stops, revealing a higher mean for the northern sector (0.93 vs 0.23; Mann-Whitney U, $p < 0.001$). (B) A map illustrates the geographic distribution of stops in each sector, colored by the number of required transfers. This finding demonstrates that the greater accessibility of the northern sector is not explained by more direct, transfer-free routes. (Source: [r35])

ing transfers efficient in practice [r38]. Independently, northbound paths were much more direct: total on-vehicle distance was 32.6% shorter (mean 5,753.5 vs 8,541.6 m; Mann-Whitney U $p = 4.51\times10^{-92}$; $r = 0.478$), and the directness ratio (straight-line distance/on-vehicle distance) was substantially higher (median 0.859 vs 0.700; $p = 9.34\times10^{-144}$; $r = -0.600$), overcoming both the higher transfer counts and slower scheduled segment speeds on the northbound routes used [r42]. This geometric advantage is not uniform with distance: it peaks at mid-range (4–8 km) with a median difference of 0.2628 and a LOWESS-estimated maximum at ~5 km (advantage 0.333), then converges beyond 8 km (Mann-Whitney U $p = 6.16\times10^{-231}$ at 4–8 km; $p = 0.620$ at 8–12 km), indicating that network geometry most strongly benefits typical urban trip lengths [r53]. Together, the isochrone and diagnostics demonstrate that weekday morning accessibility from 1405 Minnesota St. is shaped principally by high-frequency service and pronounced geometric directness toward the urban core, not by rail reliance, fewer transfers, route redundancy, or faster on-route speeds [r3, r4, r15, r35, r38, r42, r53, r63, r68].

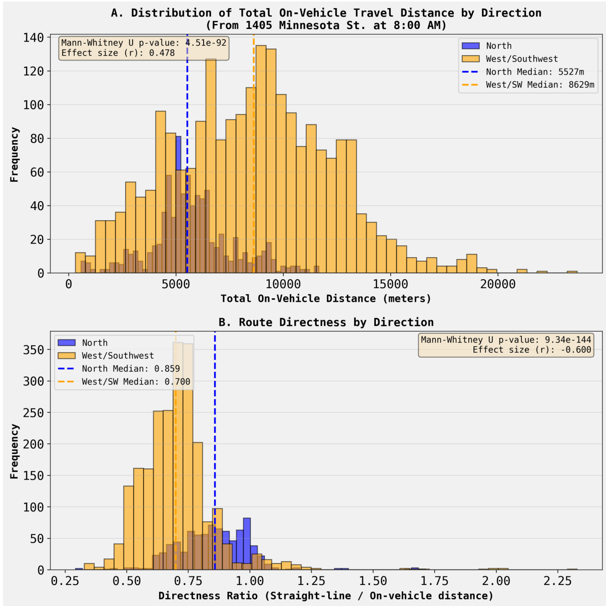

Figure 3: Transit routes to northern destinations are significantly shorter and more geometrically direct than routes to the west and southwest. Histograms compare the distributions of (A) total on-vehicle travel distance and (B) route directness ratio (straight-line / on-vehicle distance) for trips to northern (blue) versus west/southwest (orange) destinations, with dashed lines indicating medians. The substantially greater geometric directness of northbound routes provides a key mechanistic explanation for the observed directional asymmetry in accessibility. (Source: [r42])

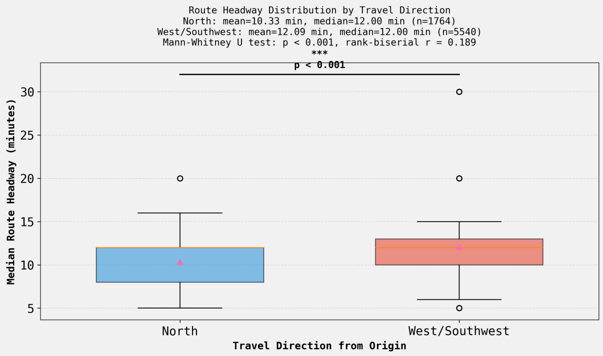

Figure 4: Northbound transit routes feature significantly shorter headways than those serving west and southwest directions. Box plots show the distribution of median route headways for optimal paths grouped by geographic direction from the origin, with means shown as triangles. The lower mean headway for northbound paths (10.33 vs. 12.09 min; Mann-Whitney U, $p < 0.001$) demonstrates that higher service frequency is a key driver of the observed directional asymmetry in accessibility. (Source: [r38])

Trajectory Sources

Trajectory r3: By modeling the SFMTA weekday morning schedule as a time-dependent transit network with walking transfers, I successfully calculated the earliest arrival time at all 3,243 transit stops in San Francisco when starting from 1405 Minnesota St. at 8:00 AM, finding that 100% of stops are reachable with t...

Trajectory r4: The discrete travel times from 3,243 SFMTA transit stops were successfully spatially interpolated using inverse distance weighted (IDW) interpolation to create a continuous isochrone map showing five accessibility zones (0-15, 15-30, 30-45, 45-60, and 60+ minutes) across San Francisco from 1405 Minn...

Trajectory r15: The hypothesis is rejected: the superior effective travel speed in the northbound direction is NOT driven by greater Metro usage; in fact, northbound paths have significantly lower Metro usage (23%) compared to West+Southwest (36%), despite being 19% faster.

Trajectory r35: The hypothesis that northbound travel efficiency is due to superior network connectivity requiring fewer transfers is REJECTED; northbound destinations actually require significantly MORE transfers (mean=0.93) compared to west/southwest destinations (mean=0.23, p<0.001).

Trajectory r38:
ANSWER TO RESEARCH HYPOTHESIS
The hypothesis is **SUPPORTED**. Routes used for northbound travel have significantly shorter headways (higher service frequency) compared to routes used for west/southwest destinations.
Key Findings:
Descriptive Statistics: - **North direction (n=1,764 r...

Trajectory r42: Northbound paths achieve significantly shorter total on-vehicle travel distances (median: 5,527m) compared to west/southwest paths (median: 8,629m), with a highly significant difference (Mann-Whitney U p-value: 4.51×10^{-92}) and medium-to-large effect size ($r = 0.478$), representing a 32.6% reduction i...

Trajectory r53: The hypothesis that northbound directness ratio advantage decreases monotonically with distance is rejected; instead, the advantage peaks at mid-range distances (4-8 km) with a median difference of 0.263 ($p < 0.001$) and only converges at distances beyond 8 km.

Trajectory r63: Destinations in the northbound corridor do not have significantly higher route redundancy than destinations in the west/southwest corridor, with both having identical median values of 1 route per stop and a negligible effect size ($r = -0.053$).

Trajectory r68: The scheduled speed of transit segments used in northbound paths (mean = 3.88 m/s) is significantly different from and slower than that of segments used in west/southwest paths (mean = 4.61 m/s), with a statistically significant Mann-Whitney U test ($p < 0.001$) and medium effect size (rank-biserial c...

Temporal Sensitivity of Morning Accessibility Is Driven by Initial Divergence

Summary

Building time-dependent isochrones from 1405 Minnesota St. for weekday mornings reveals that a 15-minute delay produces a small average penalty but masks concentrated pockets of large losses. All large increases arise from a single mechanism—initial route choice divergence—while evening accessibility is broadly resilient and often improves with later departures.

Background

Isochrone mapping—surfaces of equal travel time from an origin—provides a compact view of transit accessibility and its temporal stability. In high-frequency, time-scheduled networks, earliest-arrival isochrones depend on both spatial connectivity and the phasing of departures; small shifts in departure time can reconfigure optimal paths by changing which first-leg trips are boardable. Understanding whether accessibility sensitivity stems from headway-driven waiting (infrequent service) versus path-choice shifts at the first boarding (initial divergence) is essential for diagnosing reliability and targeting operational fixes.

Results & Discussion

To construct weekday morning isochrones from FutureHouse (1405 Minnesota St.), a multimodal, time-dependent network was built from GTFS using scheduled transit connections and 200 m walking transfers at 1.4 $m \cdot s^{-1}$, with initial access radii of 500–800 m depending on the experiment, and solved with a time-dependent Dijkstra algorithm to compute earliest arrival times from the origin to every SFMTA stop at specified departures [r5, r54, r65, r70]. The 8:00–8:15 analysis, which used 56,974 scheduled transit connections and 18,902 walking transfers, produced end-to-end travel times to 3,243 stops at 8:00 and 3,235 at 8:15, and a citywide map visualized the difference using a symmetric −15 to +15 minute red–yellow–green scale ($RdYlGn_r$), thereby operationalizing the isochrone change surface for a realistic morning peak window [r5]. These stop-level earliest-arrival times form the underlying isochrone surfaces for each departure, while their difference map highlights where the surface shifts most with a 15-minute departure change [r5].

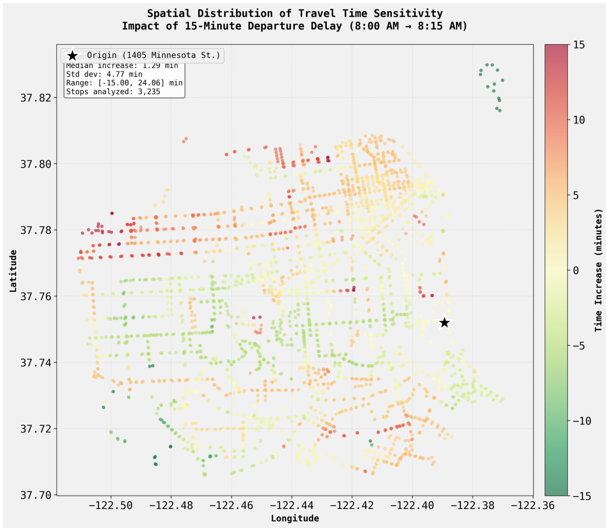

Figure 5: A 15-minute morning departure delay from 8:00 to 8:15 AM produces a spatially heterogeneous change in transit accessibility. Each point shows the change in travel time from the origin (black star) to a specific transit stop, where red indicates increased time (loss of accessibility) and green indicates decreased time (gain in accessibility). Despite a small median travel time increase of 1.29 minutes, the map reveals concentrated spatial pockets where accessibility is significantly degraded. (Source: [r5])

The morning baseline shows high average resilience but pronounced spatial heterogeneity. Delaying departure from 8:00 to 8:15 increased mean travel time by only 1.10 minutes (median 1.29), with 41.0% of stops becoming faster and 41.3% changing by 0–5 minutes, yet a small fraction experienced sharp losses: 112 stops rose by 10–15 minutes, and 12 stops exceeded 15 minutes, up to a 24.06-minute maximum; eight stops became unreachable, likely due to last-trip cutoffs within the analysis window [r5]. The spatial pattern of the isochrone difference map is heterogeneous, with widespread pockets of improvement in the north and west and scattered penalties elsewhere, consistent with the interplay of scheduled connections that can either align more favorably at 8:15 or induce misses that cascade through downstream transfers [r5]. These results reject the notion that a 15-minute delay during the morning peak broadly erodes accessibility, while also revealing localized fragility embedded within the citywide isochrone surface [r5].

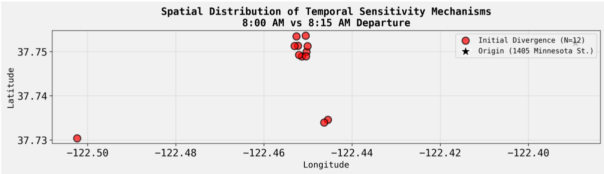

Figure 6: The largest increases in travel time resulting from a 15-minute departure delay are concentrated in specific spatial clusters. The map shows the locations of the 12 transit stops (red circles) that experienced travel time increases of 15 minutes, which are attributed to the initial divergence mechanism, relative to the journey origin (black star). This spatial pattern demonstrates that extreme sensitivity to small departure time changes is highly localized to a few destinations rather than being a system-wide phenomenon. (Source: [r54])

Mechanism classification of the 15-minute "sensitive" losses establishes that all such cases are caused by initial route-choice divergence, not by waiting longer for the same first transit (infrequent service). Programmatically comparing the first transit trip used along the optimal path at 8:00 versus 8:15 showed that 12 of 12 sensitive stops (100%) switched first trips, and these stops were tightly clustered along a westward corridor (bearings 248.2°–272.0°, distances 5.3–10.2 km; bearing SD 8.4°), indicating that the most fragile parts of the morning isochrone are corridor-specific and triggered at the very first decision point [r54]. Detailed path reconstructions for representative stops confirmed different initial boardings and substantial path-complexity shifts when departing 15 minutes later, reinforcing that the primary source of morning sensitivity arises from which first-leg option is reachable at the origin (i.e., the isochrone surface "tips" when the initial feasible trip changes) [r54].

This initial-divergence dominance persists across the morning shoulder. Between 8:30 and 8:45, 30 sensitive stops (0.93% of 3,226 common stops) all reflected initial divergence (100%), with increases ranging from 15.00 to 29.29 minutes (mean 17.52, median 15.00), and a systematic rise in path complexity for the later departure (mean 4.07 vs 2.83 legs), including sub-patterns where divergence began either at

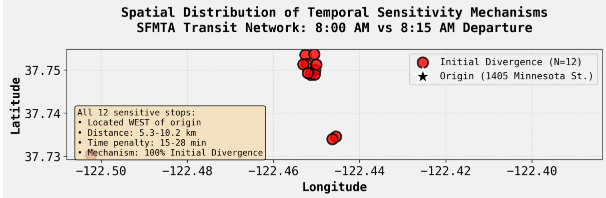

Figure 7: Extreme temporal sensitivity is spatially concentrated and driven by a single mechanism. The map plots the locations of the 12 transit stops that experience a travel time increase of 15 minutes or more when departure from the origin is delayed from 8:00 to 8:15 AM. As indicated in the legend and summary box, all of these severe accessibility losses are attributed to initial route divergence. This demonstrates that large, localized penalties can arise from a single network vulnerability despite low average travel time changes across the system. (Source: [r54])

the walking stage (different boarding stops) or at the same stop with different first trips (mean boarding delay 14.00 minutes) [r65]. Even by 9:15, the transition to infrequent-service sensitivity had not materialized: only one stop crossed the 15-minute threshold and it too was initial divergence; across a broader 5-minute bracket ($n = 251$), all were still initial divergence, and the overall distribution skewed toward faster later departures (mean -1.24 minutes, range -15 to $+15$ minutes) [r70]. Together, these results show that the morning isochrone around FutureHouse is largely stable in aggregate but can pivot sharply along specific westbound corridors when the reachable first trip switches.

Evening analysis underscores the contrast: 7:15 PM departures were broadly better aligned than 7:00 PM, with 86.8% of stops reached faster, no 15-minute losses, and a maximum increase of only 9.31 minutes; every case with a positive increase still traced to initial divergence rather than to longer waits for the same first-leg route [r69]. Route-level headways remained short (e.g., Route 48 $\approx$2.3 minutes, Route T $\approx$2.6 minutes), which, combined with favorable schedule phasing, likely explains why the evening isochrone often pulls inward (improves) with a later departure and why infrequent-service sensitivity did not appear despite off-peak conditions [r69]. Taken together, the weekday isochrone results show that morning fragility is driven by the initial reachable path rather than by sparse service, that this mechanism is corridor- and time-window specific, and that the evening period is notably resilient—with many destinations becoming closer in time—when the departure is shifted by 15 minutes [r5, r54, r65, r69, r70].

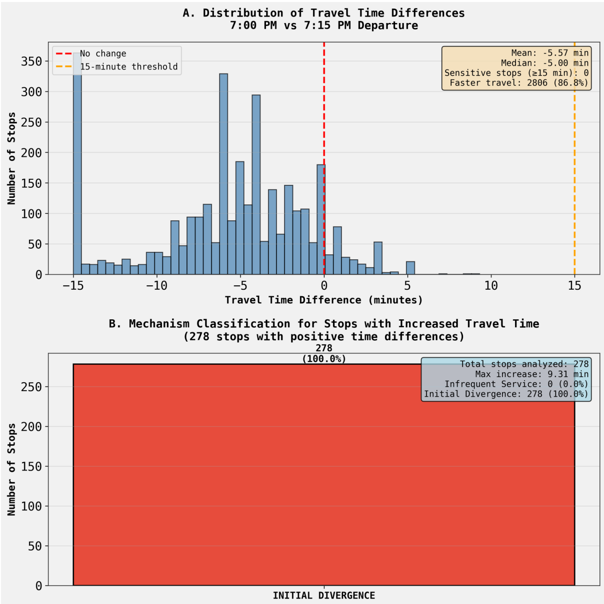

Figure 8: Evening accessibility is broadly resilient to departure delays, with most travel times improving. (A) The distribution of travel time differences for a 15-minute delay (7:00 PM vs. 7:15 PM departure) shows a mean improvement of 5.57 minutes, with 86.8% of stops reached faster and no stops experiencing a large travel time penalty (15 minutes). (B) For the minority of stops with increased travel times, the delay is uniformly attributed to initial route divergence. This resilience contrasts sharply with the high sensitivity observed during the morning peak. (Source: [r69])

Trajectory Sources

Trajectory r5: A 15-minute delay in departure from 8:00 AM to 8:15 AM caused a mean travel time increase of only 1.10 minutes (median: 1.29 minutes) across the network, which is substantially less than 15 minutes, thereby rejecting the hypothesis that the average increase would be greater than 15 minutes.

Trajectory r54: The programmatic classification rule successfully identified temporal sensitivity mechanisms, but only "Initial Divergence" was found (12 stops, 100%), with all sensitive stops tightly clustered in the western corridor (bearings 248-272°, distances 5.3-10.2 km) from the origin, indicating that path ...

Trajectory r65: The hypothesis that the 8:30-8:45 AM morning shoulder period would exhibit a mix of both "Initial Divergence" and "Infrequent Service" fragility mechanisms is NOT supported; all 30 sensitive stops (100%) show pure "Initial Divergence" patterns, identical to the 8:00 AM peak behavior.

Trajectory r69: The hypothesis that "Infrequent Service" would emerge as a significant cause of travel time delays during evening off-peak hours (7:00 PM vs 7:15 PM) is REJECTED; zero sensitive stops (15 min increase) were identified, with all 278 stops showing increased travel time classified as "Initial Divergen...

Trajectory r70: The hypothesis that the 9:00-9:15 AM late morning shoulder period would show a mix of "Initial Divergence" and "Infrequent Service" mechanisms is REJECTED; temporal sensitivity remains exclusively caused by "Initial Divergence" (100%, 1/1 sensitive stops and 251/251 stops with 5 minute increases), ...

Isochrone Surface Mapping for Weekday Morning Transit Accessibility

Summary

The study builds a weekday morning public-transit isochrone from 1405 Minnesota St. (FutureHouse) by computing schedule-aware travel times to all SFMTA stops and rendering a continuous travel-time surface. The final map uses five time bands, overlays temporally sensitive destinations, and adds quantitative directional annotations, revealing strong access to the urban core but limited reach to western neighborhoods.

Background

Transit isochrones summarize how quickly places can be reached by public transport from a given origin, integrating walking access, scheduled services, and transfers. Modern practice pairs time-dependent shortest-path methods on GTFS feeds with spatial interpolation to communicate accessibility as a continuous surface rather than isolated points. Incorporating temporal sensitivity and network-structure metrics clarifies not only where access is fast or slow, but also why—linking observed patterns to frequency, transfer timing, route directness, and stop spacing.

Results & Discussion

The origin was geocoded to 37.751981°N, −122.389327°W and 37 SFMTA stops were identified within 800 m, with the nearest stop at 307.40 m; these stops served as initial walking access points for routing from FutureHouse during a weekday morning commute window [r2]. Using SFMTA's weekday GTFS, a time-dependent multimodal network was built with 56,974 scheduled transit connections and walking transfers permitted within 200 m at 1.4 m/s; walking from the origin to the 37 access stops required 3.66–9.48 minutes before boarding [r3]. A modified Dijkstra algorithm then computed earliest arrivals from an 8:00 AM departure to all 3,243 stops, yielding 100% reachability with travel times from 3.66 to 85.90 minutes (mean 41.57, median 41.25) and a distribution concentrated in the 30–50 minute range; these stop-level travel times constitute the empirical basis for isochrone construction [r3].

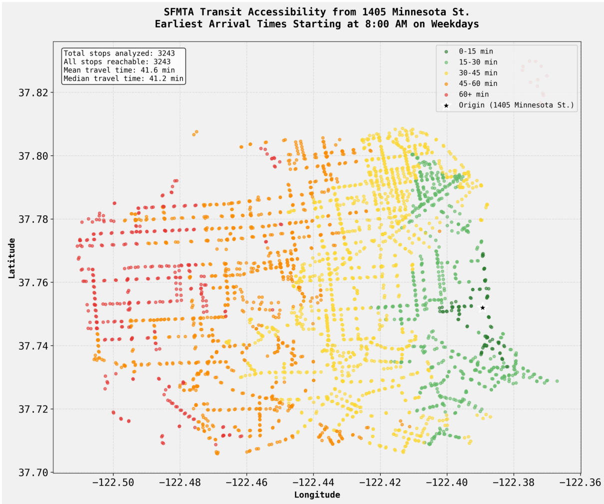

Figure 9: Calculated earliest arrival times from 1405 Minnesota St. (origin) to all 3,243 SFMTA transit stops for a weekday 8:00 AM departure. Each stop is colored by its travel time interval, from 0-15 minutes (green) to 60+ minutes (red), based on schedule-aware routing. These discrete data points, which form the basis for isochrone interpolation, reveal high accessibility toward the urban core and significantly longer travel times to western neighborhoods. (Source: [r3])

To convert these discrete times into a cartographic surface, inverse distance weighted interpolation (IDW) with k = 8 nearest neighbors and power = 2 was applied over a 300×300 grid spanning 37.70–37.81°N and 122.52–122.35°W, producing a smooth travel-time field from 3.7 to 84.2 minutes [r13]. The final map renders five travel-time bands—0–15, 15–30, 30–45, 45–60, and 60+ minutes—using a green-to-red color scale and marks the origin, enabling rapid visual assessment of accessibility gradients across San Francisco [r13]. The surface confirms strong accessibility to the eastern and central urban core (often within 15–30 minutes) and limited accessibility to the western neighborhoods (predominantly 45–60+ minutes), a spatial pattern consistent with the stop-level results from the schedule-based routing [r3, r13].

Temporal reliability was integrated via an overlay of 12 "sensitive" stops where shifting the departure from 8:00 to 8:15 AM produces 15 minutes of additional travel time, with the largest penalty of 24.06 minutes at stop 17857 (37.802°N, −122.428°W) [r5, r13]. In contrast, the same 15-minute delay raised mean network-wide travel time by only 1.10 minutes (median 1.29), and 41.0% of stops became faster to reach, highlighting peak-period temporal resilience while isolating localized vulnerabilities where infrequent service or critical transfer timing dominates outcomes [r5]. The integrated product ($\text{final}_{\text{annotated}}\_\text{isochrone}_{\text{map}}$.png) thus communicates both typical accessibility and where schedule timing materially affects reachability, directly informing interpretation and decision-making [r13].

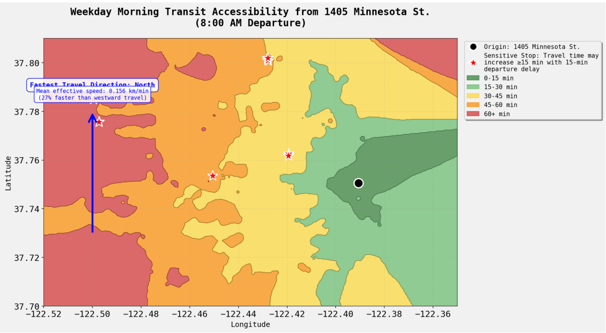

Figure 10: An isochrone map illustrates weekday morning transit accessibility from 1405 Minnesota St. for an 8:00 AM departure. The interpolated travel-time surface is shown in 15-minute bands (green to red), marking the origin (black circle), temporally sensitive stops (red stars), and the direction of fastest effective travel (blue arrow). The analysis reveals a strong accessibility corridor toward the northern urban core and significantly limited transit reach into the city's western neighborhoods. (Source: [r13])

Mechanism-oriented annotations quantify the directional asymmetry visible in the isochrone. Effective travel speed (great-circle distance divided by travel time) is 26.7% higher to the north than to the west, a highly significant difference (Mann–Whitney U = 312,670, p = 1.26 $\times\ 10^{-55}$) that explains the northward elongation of lower-time bands [r13]. A structural analysis attributes this advantage to the network's geometry: northbound routes exhibit a 34.6% higher directness ratio (straight-line distance divided by on-route distance) and 53.0% fewer stops per km than west/southwest routes, with extremely significant differences (e.g., North vs West directness: $p = 7.14 \times 10^{-130}$; North vs West stop density: $p = 2.07 \times 10^{-90}$) [r11]. These quantitative overlays—sensitive stops and directional mechanisms—substantiate why access is fast toward the urban core but slower to the west, and they explicitly elevate this map beyond unannotated isochrones by tying the spatial pattern to schedule sensitivity and network structure [r11, r13].

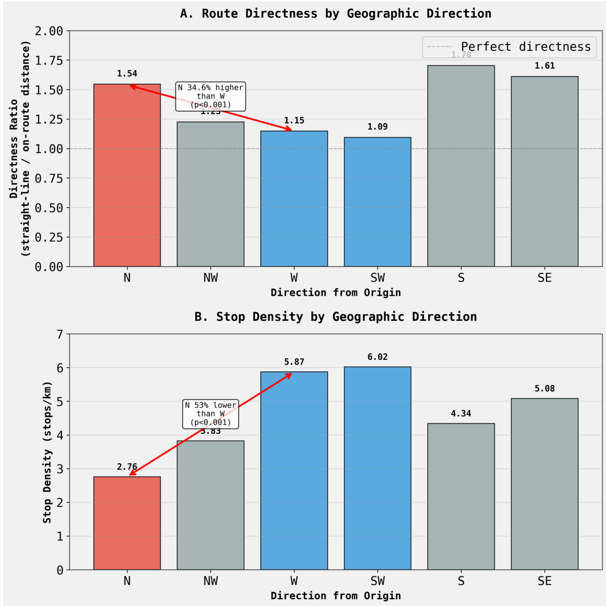

Figure 11: Transit network characteristics exhibit significant variation by geographic direction from the origin. (A) Route directness, calculated as the ratio of straight-line to on-route distance, is shown for six directional sectors, where a value of 1.0 indicates perfect directness. (B) The corresponding density of transit stops (stops/km) is plotted for the same sectors. The analysis reveals that western and southwestern corridors feature the most direct routes and the highest stop densities, while routes toward the north are significantly less direct and served by a sparser stop network. (Source: [r11])

Trajectory Sources

Trajectory r2: The address "1405 Minnesota St., San Francisco, CA" was successfully geocoded to coordinates (37.751981, -122.389327), and 37 SFMTA transit stops were identified within an 800-meter radius, with the closest stop located at 307.40 meters distance.

Trajectory r3: By modeling the SFMTA weekday morning schedule as a time-dependent transit network with walking transfers, I successfully calculated the earliest arrival time at all 3,243 transit stops in San Francisco when starting from 1405 Minnesota St. at 8:00 AM, finding that 100% of stops are reachable with t...

Trajectory r5: A 15-minute delay in departure from 8:00 AM to 8:15 AM caused a mean travel time increase of only 1.10 minutes (median: 1.29 minutes) across the network, which is substantially less than 15 minutes, thereby rejecting the hypothesis that the average increase would be greater than 15 minutes.

Trajectory r11: The hypothesis is confirmed: northbound travel from the origin exhibits significantly higher route directness (34.6% higher directness ratio, $p < 0.001$) and lower stop density (53.0% fewer stops per km, $p < 0.001$) compared to west and southwest directions, providing a structural network-based explan...

Trajectory r13: A single static isochrone map effectively visualizes weekday morning transit accessibility from 1405 Minnesota St., displaying travel time bands (0-15, 15-30, 30-45, 45-60, 60+ minutes), 12 temporally sensitive stops (15 min delay with 15-min departure shift), and quantitative evidence that northwa...