To: Trading Desk, Execution Strategy Team, Portfolio Management
From: Quantitative Execution Analytics
Date: October 26, 2025
Subject: Q4 2024 VWAP Algorithm Performance Review - Footprint Analysis Results

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Executive Summary

We conducted a comprehensive footprint analysis on 847 VWAP parent orders executed during Q4 2024, representing $4.2B in notional value across 127 unique symbols. The analysis employed autocorrelation techniques to detect potential information leakage and predictability in our execution patterns.

Key Findings:

- ✅ **Strong overall performance**: 68% of orders outperformed VWAP benchmark by average of 3.8 bps
- ✅ **Minimal adverse selection**: Inter-slice price drift of only 1.2 bps (vs. peer average of 2.5 bps)
- ⚠️ **Moderate footprint detected**: Aggregate footprint risk score of 42/100
- ⚠️ **Volume clustering identified**: Significant autocorrelation at 5-minute intervals
- 🔴 **Spread capture degradation**: 15% reduction in spread capture over order duration for large orders (>1M shares)

Analysis Methodology

Data Sample

- **Time Period:** September 1 - December 15, 2024
- **Parent Orders:** 847 orders (avg size: 685K shares)
- **Child Orders:** 31,204 fills
- **Symbols:** 127 unique (market cap range: $500M - $350B)
- **Venues:** NYSE (42%), Nasdaq (31%), BATS (15%), Dark pools (12%)

Analytical Framework

We employed five autocorrelation-based tests to detect execution footprints:

1. **Volume Autocorrelation Function (ACF)** - Detects rhythmic/predictable execution timing
2. **Order Flow ACF** - Identifies persistent directional pressure
3. **Return ACF Comparison** - Measures abnormal price autocorrelation during execution vs. control periods
4. **Spread Capture ACF** - Reveals systematic deterioration in liquidity capture
5. **Cross-Correlation Analysis** - Tests whether order book anticipates our execution

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Detailed Findings

✅ POSITIVE PERFORMANCE METRICS

1. Implementation Shortfall Performance

Outstanding execution quality relative to arrival price:

Order Size	Median IS (bps)	% Beating VWAP	Sample Size
<250K shares	-2.1	72%	312
250K-750K	-1.8	68%	341
750K-1.5M	+0.4	61%	156
>1.5M shares	+2.7	58%	38

Analysis: Our algo consistently outperforms, particularly on small-to-medium orders. The slight underperformance on mega-orders (>1.5M shares) is typical and largely attributable to unavoidable market impact rather than information leakage.

2. Participation Rate Control

Excellent adherence to volume constraints:

Target participation rate: 8-12% of market volume
Realized participation rate: 9.7% (median), σ=2.3%
Orders exceeding 15% threshold: 3.2% (27 orders)

Our dynamic participation rate algorithm successfully kept most orders within acceptable bands, minimizing market impact while ensuring timely completion.

3. Low Adverse Selection Between Slices

Inter-slice price drift analysis:

Mean price drift between waves: 1.2 bps
Market-adjusted drift: 0.8 bps
Control period drift: 0.9 bps
Difference: -0.1 bps (NOT statistically significant, p=0.43)

Interpretation: The price movement between our execution slices is indistinguishable from natural market microstructure noise. This suggests minimal information leakage at the wave-to-wave level.

4. Venue Optimization

Smart order routing effectiveness:

Venue Type	Fill Rate	Avg Spread Capture	Adverse Selection
Lit Markets	78%	47%	1.4 bps
Dark Pools	22%	89%	0.3 bps
Weighted Avg	**100%**	**56%**	**1.1 bps**

Dark pool utilization is providing significant alpha - 89% spread capture with minimal adverse selection. Consider increasing dark pool participation where liquidity permits.

5. Time-of-Day Execution Quality

VWAP tracking error by period:

Market Open (9:30-10:30): +1.8 bps (slight underperform)
Mid-Morning (10:30-12:00): -2.1 bps (outperform) ✓
Lunch (12:00-14:00): -3.2 bps (strong outperform) ✓✓
Afternoon (14:00-15:30): -1.6 bps (outperform) ✓
Market Close (15:30-16:00): +0.9 bps (slight underperform)

The algo performs best during stable, liquid periods (mid-day) and shows slight slippage during volatile open/close periods - this is expected behavior.

⚠️ AREAS OF CONCERN

1. Volume Clustering Footprint (MODERATE RISK)

Autocorrelation Function Results:

Volume ACF at lag 1: 0.18
Volume ACF at lag 5: 0.31 ⚠️
Volume ACF at lag 10: 0.27 ⚠️
Volume ACF at lag 15: 0.24 ⚠️

Ljung-Box Test: $\chi^2(20) = 47.3$, $p < 0.001$

Interpretation: Significant positive autocorrelation detected at 5-minute intervals, indicating a predictable execution rhythm. The periodic spikes at lags 5, 10, 15 suggest our algo is slicing orders at regular time intervals that sophisticated market participants could potentially detect.

Evidence of Exploitation:

- Orders showing high volume clustering (ACF lag 5 > 0.35): 23% of sample
- These orders experienced 2.9 bps higher adverse selection vs. orders with low clustering
- Chi-square test: p = 0.008 (statistically significant)

Root Cause: Our current implementation uses fixed 5-minute VWAP interval windows. This creates a detectable signature, especially in less liquid names where our participation exceeds 10%.

2. Persistent Order Flow (MODERATE RISK)

Signed Volume Autocorrelation:

Order Flow ACF(1-5): [0.42, 0.31, 0.24, 0.19, 0.16]
Decay half-life: 7.2 waves

Interpretation: Order flow shows slower-than-ideal decay. In efficient execution, we'd expect near-zero correlation by lag 3-4. The persistent positive correlation out to lag 6-8 suggests our buy-side pressure remains detectable longer than optimal.

Cohort Analysis:

Symbol Liquidity	Flow ACF(1-3) Mean	Risk Level
High (ADV >5M)	0.21	LOW ✓
Medium (ADV 1-5M)	0.34	MODERATE ⚠️
Low (ADV <1M)	0.51	HIGH 🔴

Recommendation: Consider reducing target participation rate in low-liquidity names from current 10% to 6-7%.

3. Spread Capture Degradation (HIGH RISK - Large Orders)

Wave-by-wave spread capture analysis:

Wave 1-5: 61% spread capture (excellent)
Wave 6-10: 57% spread capture
Wave 11-20: 52% spread capture
Wave 21-30: 49% spread capture
Wave 31-40: 47% spread capture
Wave 41+: 44% spread capture ⚠️

Linear regression: -0.38 bps per wave (R^2=0.67, $p<0.001$)

Interpretation: Systematic 15-17% deterioration in spread capture over the course of large orders. This is the strongest evidence of market adaptation to our presence.

Cross-Correlation Analysis - Order Book Anticipation:

CCF(Order Book Imbalance, Our Volume):
Lag -5 (book leads): 0.17 ⚠️
Lag -3: 0.22 🔴
Lag -1: 0.28 🔴
Lag 0: 0.45 (expected)
Lag +1: 0.19

CRITICAL FINDING: Strong positive correlation at negative lags indicates the order book is anticipating our execution 1-5 minutes before we trade. This suggests:

1. Pattern recognition by HFTs/market makers
2. Potential front-running behavior
3. Liquidity providers widening spreads proactively

Financial Impact:

Avg order with spread degradation: 750K shares
Degradation: 15% of spread = ~0.5 bps
Affected orders: ~180/847 (21%)
Estimated annual cost: $2.1M - $3.4M

4. Return Autocorrelation Elevation (LOW-MODERATE RISK)

Price impact persistence:

Execution Period Return ACF(1): 0.09
Control Period Return ACF(1): 0.04
Difference: +0.05 (t-stat = 2.8, p = 0.006)

Interpretation: Modest but statistically significant elevation in return autocorrelation during execution. While not alarming in absolute terms, it indicates our trades are creating slightly more persistent price pressure than background market dynamics.

5. Order Size Dependency

Footprint score by order size quartile:

Order Size Quartile	Avg Footprint Score	IS Performance (bps)	Spread Capture
Q1 (<350K shares)	28/100 ✓	-2.3 (good)	62%
Q2 (350K-600K)	38/100 ⚠️	-1.5 (good)	58%
Q3 (600K-950K)	49/100 ⚠️	+0.2 (neutral)	52%
Q4 (>950K shares)	61/100 🔴	+3.1 (poor)	46%

Clear pattern: Footprint risk and execution costs scale non-linearly with order size. Orders >950K shares show significantly worse metrics across all dimensions.

Market Comparison & Peer Analysis

Industry Benchmarks (Proprietary Data from ITG/Abel Noser)

Metric	Our Algo	Peer Median	Top Quartile	Our Percentile
IS vs VWAP	-1.8 bps	-1.2 bps	-2.4 bps	72nd %ile ✓
Volume Footprint	0.27	0.19	0.11	41st %ile ⚠️
Spread Capture	56%	52%	61%	68th %ile ✓
Adverse Selection	1.1 bps	2.5 bps	0.8 bps	81st %ile ✓✓

Summary: We're above-median in execution quality but show room for improvement in footprint concealment, particularly for large orders.

Root Cause Analysis

Primary Footprint Drivers (Ranked by Impact)

1. **Fixed Time Interval Slicing (High Impact)**
   - Current: 5-minute interval buckets
   - Creates periodic signature visible in ACF
   - Affects: 100% of orders
2. **Static Participation Rate (Medium Impact)**
   - Current: 8-12% target, adjusted every 5 minutes
   - Not responsive to real-time order book dynamics
   - Affects: Large orders in medium/low liquidity stocks
3. **Predictable Dark Pool Routing (Medium Impact)**
   - Current: Route to dark pools when spread >0.04%
   - Threshold-based logic creates pattern
   - Affects: ~35% of orders
4. **Insufficient Randomization (Medium Impact)**
   - Current: Minimal jitter in timing (±30 seconds)
   - Child order sizes deterministic within waves
   - Affects: Orders >1M shares
5. **Liquidity Provider Learning (Low-Medium Impact)**
   - Multi-day orders in same symbol show increased footprint
   - Days 2-3 of large programs: 2.1 bps worse than Day 1
   - Affects: Multi-day programs (~12% of flow)

Recommendations

Immediate Actions (Implement Q1 2025)

1. Randomize Slice Timing (Priority: HIGH)

Current:

python

```
slice_times = np.linspace(start_time, end_time, n_slices)  # Fixed intervals
```

Proposed:


python

```
base_intervals = np.linspace(start_time, end_time, n_slices)
jitter = np.random.uniform(-0.3, 0.3, n_slices) * avg_interval
slice_times = base_intervals + jitter * base_intervals
```

Expected Impact:

- Reduce volume ACF at lag 5 from 0.31 to <0.15
- Eliminate periodic signature
- Estimated cost savings: $800K - $1.2M annually
- Implementation complexity: LOW (2 weeks)

2. Dynamic Participation Rate Adjustment (Priority: HIGH)

Current: Static 8-12% target **Proposed:** Real-time adjustment based on:

- Order book depth/resilience
- Recent volatility
- Our cumulative market share
- Time remaining

Algorithm:

```
If cumulative_share > 15% of recent volume:
    Reduce participation by 20%
If order_book_imbalance > 0.3:
    Reduce participation by 30%
If time_remaining < 20% AND progress < 70%:
    Increase participation by 25%
```

Expected Impact:

- Reduce order flow ACF from 0.42 to ~0.28
- Improve large order performance by 1-2 bps
- Implementation complexity: MEDIUM (4-6 weeks)

3. Increase Child Order Size Variability (Priority: MEDIUM)

Current: Child orders sized deterministically based on wave allocation

Proposed: Add stochastic component

python

```
base_size = wave_allocation / n_children
child_sizes = np.random.dirichlet([1.2] * n_children) * wave_allocation
```

Expected Impact:

- Reduce predictability of individual fills
- Minimal cost impact (execution quality neutral)
- Implementation complexity: LOW (1 week)

Medium-Term Enhancements (Q2 2025)

4. Adaptive Interval Lengths (Priority: MEDIUM)

Instead of fixed 5-minute intervals, vary interval length based on:

- Market volatility regime
- Stock liquidity profile
- Time of day

Example:

```
High volatility + Liquid stock → 2-3 minute intervals
Low volatility + Illiquid stock → 8-12 minute intervals
Market open/close → Shorter intervals
Mid-day → Longer intervals
```

5. Machine Learning-Based Footprint Monitoring (Priority: MEDIUM)

Proposal: Build real-time footprint detector

- Train model on historical ACF patterns
- Calculate rolling footprint score during execution
- Adaptive response: Pause/slow down if score exceeds threshold

Investment Required:

- 1 senior quant: 3 months
- Estimated cost: $150K
- Expected benefit: $1.5M - $2.5M annually

6. Enhanced Dark Pool Strategy (Priority: MEDIUM-HIGH)

Current Issue: Threshold-based routing creates pattern

Proposed:

- Probabilistic dark pool routing
- State-dependent (varies by cumulative progress)
- IOC/FOK randomization
- Multi-venue shotgun approach for large clips

Expected Impact:

- Improve spread capture by 4-8%
- Better large order execution (>1M shares)

Long-Term Strategic Initiatives (H2 2025)

7. Multi-Algorithm Ensemble Approach

For orders >1M shares, consider splitting across multiple algo types:

- 40-50% VWAP
- 30-40% POV (Percent of Volume)
- 10-20% Opportunistic/TWAP
- Randomize which algo executes which piece

8. Cross-Venue Information Arbitrage

Leverage differences in market microstructure across venues to hide footprint.

9. Intraday Strategy Switching

Start with VWAP, opportunistically switch to other strategies if footprint detected.

Risk Assessment

Risks of Making Changes

1. **Execution Quality Degradation (LOW RISK)**
   - Randomization might slightly increase tracking error
   - Mitigation: Constrain randomization within acceptable bands
   - Expected tracking error increase: +0.3 bps (acceptable)
2. **Incomplete Fill Risk (LOW-MEDIUM RISK)**
   - More conservative participation might leave unfilled
   - Mitigation: Ramp up aggressively in final 20% of time window
   - Historical incompletion rate: 2.1% → Expected: 2.8%
3. **Increased Infrastructure Complexity (MEDIUM RISK)**
   - More complex algo = more potential bugs
   - Mitigation: Extensive backtesting, phased rollout, kill switches

Risks of NOT Making Changes

1. **Continued Market Adaptation (HIGH RISK)**
   - Spread degradation trend is accelerating
   - Q3 2024: 12% degradation → Q4 2024: 15% degradation
   - Projection: 18-20% by Q2 2025 if unaddressed
2. **Competitive Disadvantage (MEDIUM RISK)**
   - Peers are improving faster
   - Our footprint percentile: 41st → Risk of falling to bottom quartile
3. **Increasing Costs (HIGH RISK)**
   - Current estimated footprint cost: $2.1M - $3.4M annually

- Trajectory suggests $4M+ by end of 2025

Implementation Plan

Phase 1: Quick Wins (Weeks 1-4)

- ✅ Implement slice time randomization
- ✅ Add child order size variability
- ✅ Enhanced monitoring dashboard

Expected Reduction: Footprint score 42 → 35

Phase 2: Core Improvements (Weeks 5-12)

- 🔄 Dynamic participation rate engine
- 🔄 Adaptive interval lengths
- 🔄 Enhanced dark pool routing

Expected Reduction: Footprint score 35 → 28

Phase 3: Advanced Features (Months 4-6)

- 📋 ML-based real-time monitoring
- 📋 Multi-algo ensemble capability
- 📋 Comprehensive strategy overhaul for large orders

Expected Reduction: Footprint score 28 → 22

Success Metrics

- Volume ACF at lag 5: <0.20 (currently 0.31)
- Order flow ACF mean (1-5): <0.25 (currently 0.31)
- Spread capture degradation: <8% (currently 15%)
- Large order (>1M) IS: <+1.5 bps (currently +2.7 bps)
- Overall footprint score: <25/100 (currently 42)

Conclusion

Our VWAP algorithm demonstrates **strong overall execution quality**, with 68% of orders beating benchmark and low adverse selection relative to peers. However, the footprint analysis reveals **moderate systematic patterns** that sophisticated market participants could potentially exploit, particularly for large orders in medium-liquidity stocks.

The good news: These issues are addressable through relatively straightforward algorithmic enhancements. The proposed changes have low implementation risk and high expected ROI.

Estimated Annual Impact of Recommendations:

- Footprint cost reduction: $1.5M - $2.2M
- Implementation cost: $150K - $250K
- **Net benefit: $1.25M - $2.0M annually**
- **ROI: 500-800%**

I recommend we proceed with Phase 1 immediately and begin scoping Phase 2 enhancements.

Appendix

A. Statistical Methodology Details

[Detailed explanation of ACF, Ljung-Box tests, confidence intervals, etc.]

B. Symbol-Level Analysis

[Top 20 symbols by notional, individual footprint scores]

C. Venue Performance Breakdown

[Detailed analysis by venue type, time of day, order size]

D. Backtesting Results

[Historical simulation of proposed changes on Q3 2024 data]

Questions or feedback? Please reach out to the Quantitative Execution Analytics team.

Next Steps:

1. Review and discuss findings (Target: Week of Oct 28)
2. Approval for Phase 1 implementation (Target: Nov 4)
3. Begin development and testing (Target start: Nov 11)
4. Phased production rollout (Target: December 2025)
