Session 1:

Overview of Electronic and Algorithmic Trading

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Session I: Outline

1. Overview of Electronic and Algorithmic Trading
2. Financial Markets Landscape
3. Trading Algorithms
4. Market Order Book & Order Types
5. Smart Order Routing
6. Market Microstructure
7. Transaction Costs
8. Post-Trade Analysis (TCA)

Electronic and Algorithmic Trading

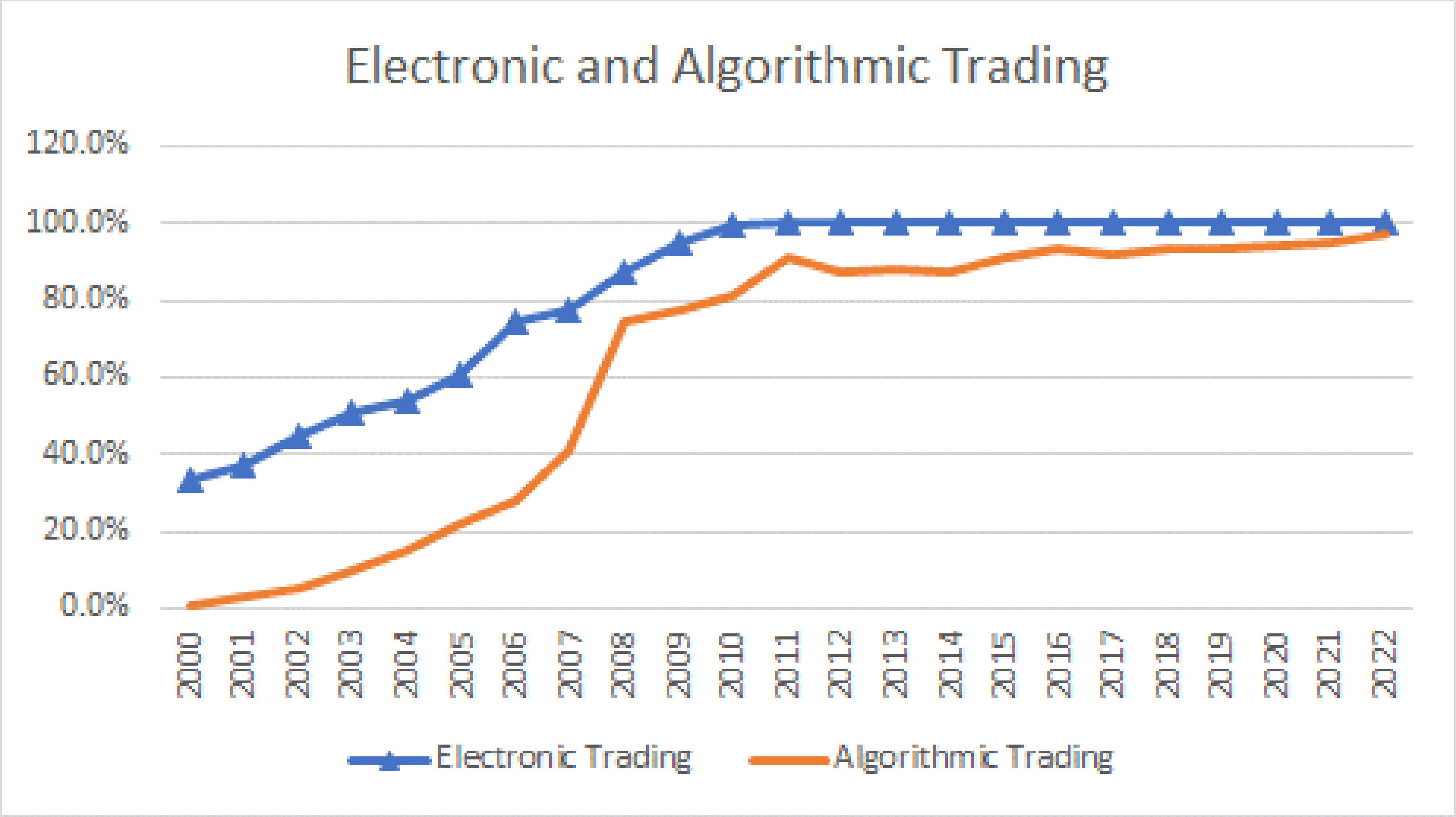
What is Electronic Trading?

- Electronic trading is the process of entering and transacting order over a computer network.
- Historically, orders were sent to brokers via phone and/or fax and were executed via human traders and manual intervention. Traders were tasked with achieving the best price for their clients and would utilize the services of specialists and market makers.
- But now,
  - Markets are completely electronic, and all trading is preformed via computers.
  - Most market trades occur via trading algorithms that are making execution decisions in real-time based on actual market conditions and stocks trends.
- Most importantly, trading algorithms are making decisions without human intervention.

What is Algorithmic Trading?

- Algorithmic trading is the computerized execution of financial instruments following a set of pre-specified trading rules and instructions.
- These instructions specify how fast or slow to transact the order in the market, and at what prices, and trading venues.
- Traditionally, investors would send their order to a broker who would then transact the order in the market using best efforts and their expertise.
- But with the changing landscape, human traders are no longer best equipped to handle the large quantity of financial data manually. Instead, human traders rely on sophisticated computer algorithms to execute orders based changing market conditions, quotes, and trends.
- Traders need to be proactive in the Algorithmic Trading environment and are required to specify trading goals based on the underlying investment objective of the fund.

Electronic and Algorithmic Trading



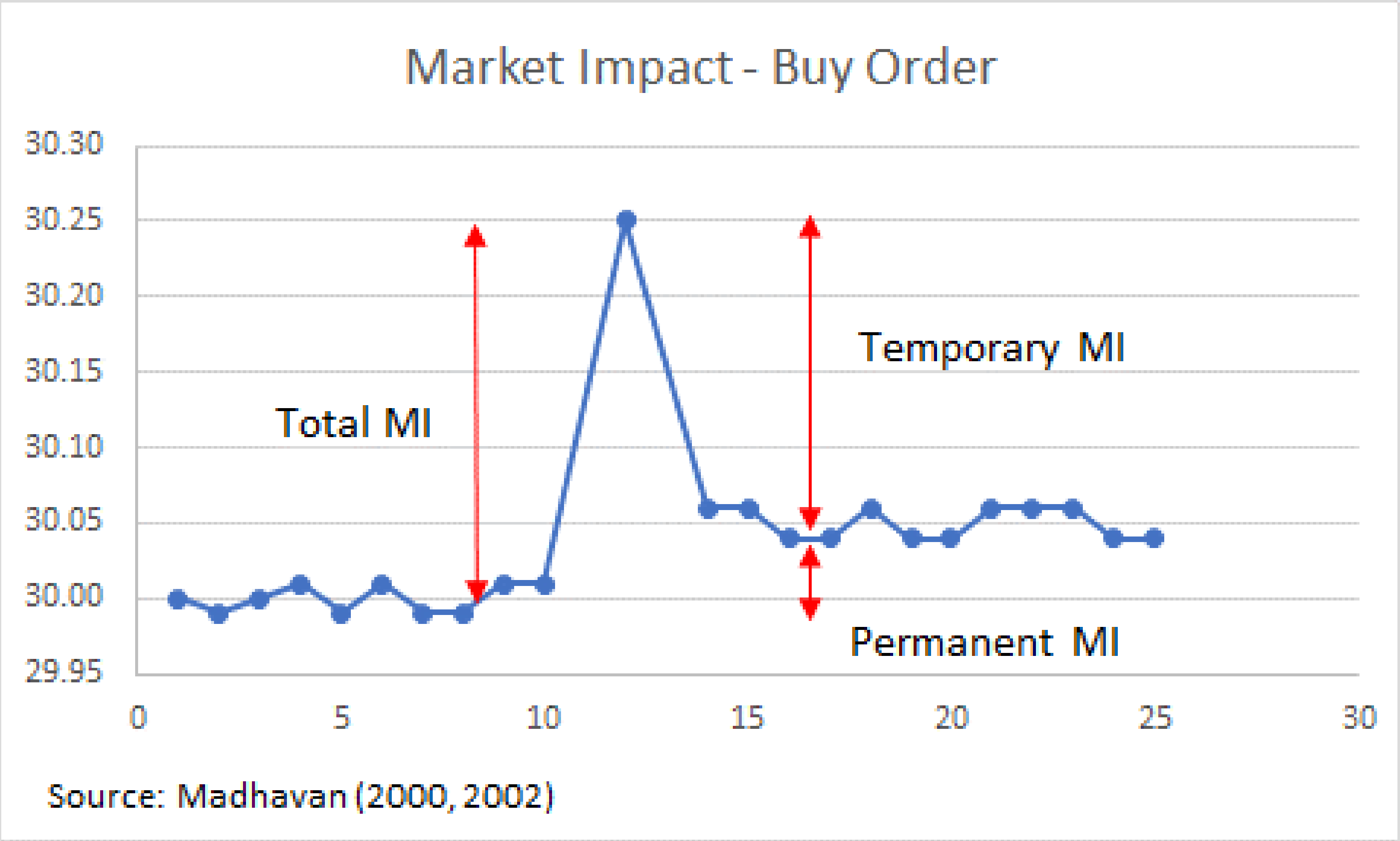
Source: Kissell Research Group (2022)

Why are Algos so Important? – where does this slide

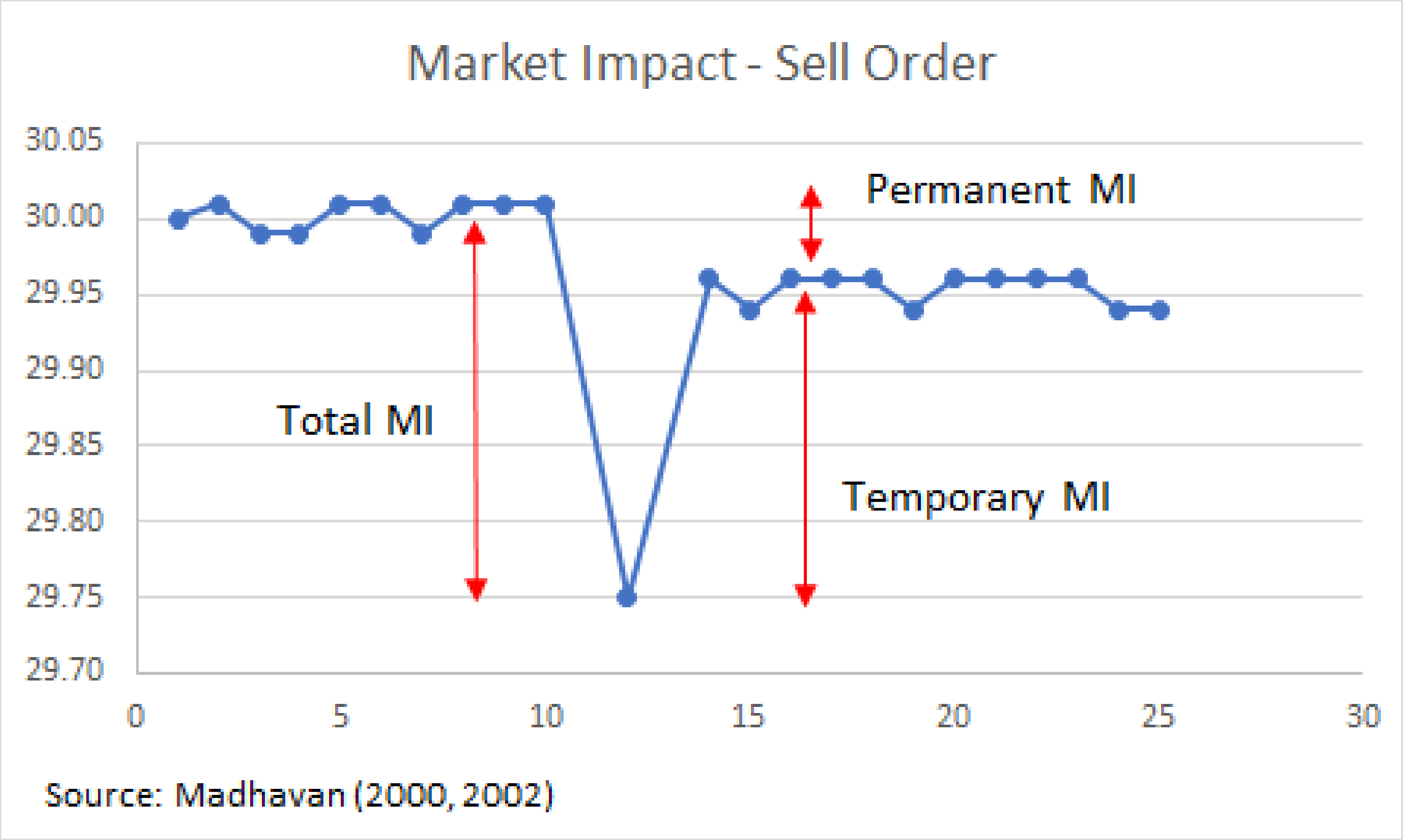
- Before we get started, it is important to say that Institutional Orders are usually very large, e.g., much more than 100 shares.
- These large orders will cause price impact in the stock you are transacting.
- For example, these buy orders cause the market price to increase and sell orders cause the market prices to decrease.
- How do institutions combat this phenomena?
    - Slice the order and trade over time.
    - Balance Market Impact and Timing Risk
- Algorithms are tasked with properly slicing the order to reduce trading cost.
- Algorithms slice orders based on:
    - 1) Time-Periods
    - 2) Volumes
    - 3) Prices

Market Impact / Price Impact

Market Impact Cost – Buy Order



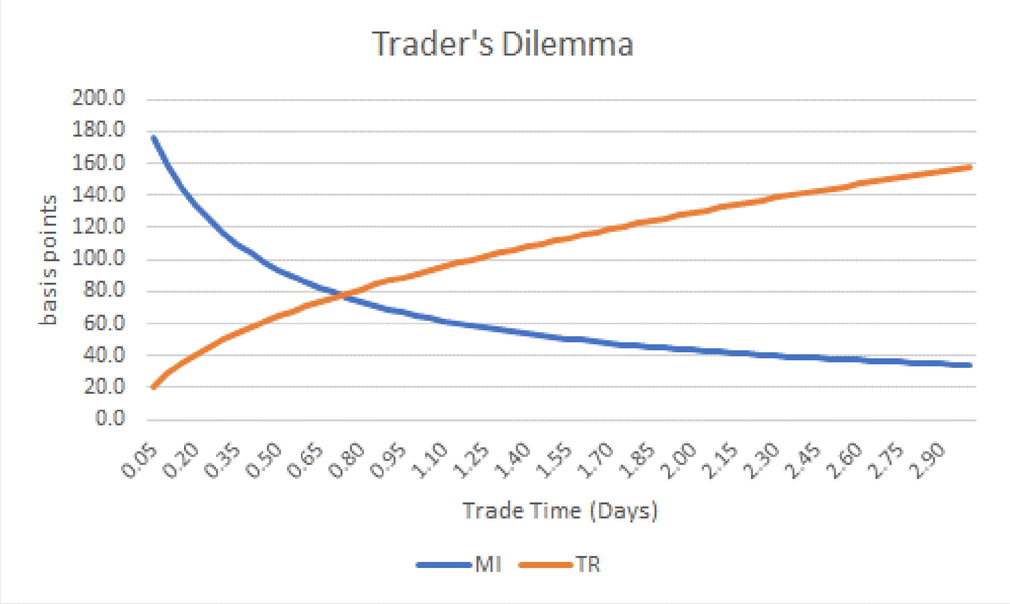
Market Impact – Sell Order



Trader's Dilemma

- Market Impact (MI) and Timing Risk (TR) are conflicting expressions.
- Market Impact is a decreasing function with trade time. Trading faster incurs higher MI and trading slower incurs less MI.
- Timing Risk is an increasing function with trade time. Trading faster incurs lower TR and trading slower incurs higher TR.

- Trader's Dilemma:
- Trading too fast will incur too much market impact cost but trading too slow will incur the order to too much market exposure risk.
- In other words, trade too fast and you move the market but trade too slow and the market moves you.



- Investors are tasked with determining the appropriate algorithm and execution strategy that will balance the tradeoff between Market Impact and Timing Risk.
- This is based on order characteristics, risk-aversion, and motivation of the investment decision.

Solving Trader’s Dilemma:

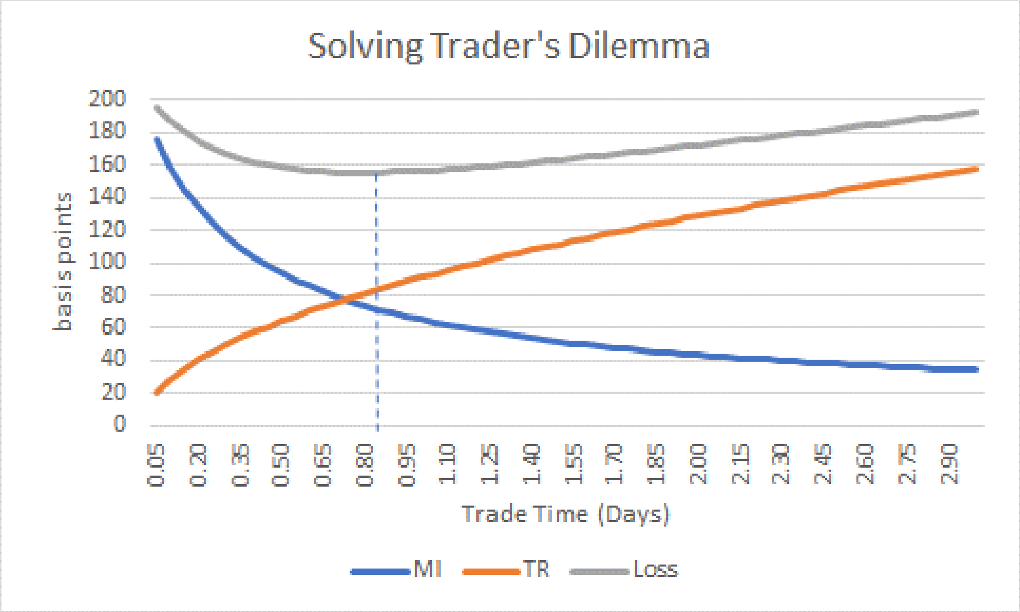
- Investors solve the Trader’s Dilemma via optimization.

$$Min \quad MI + \lambda \cdot TR$$

where,

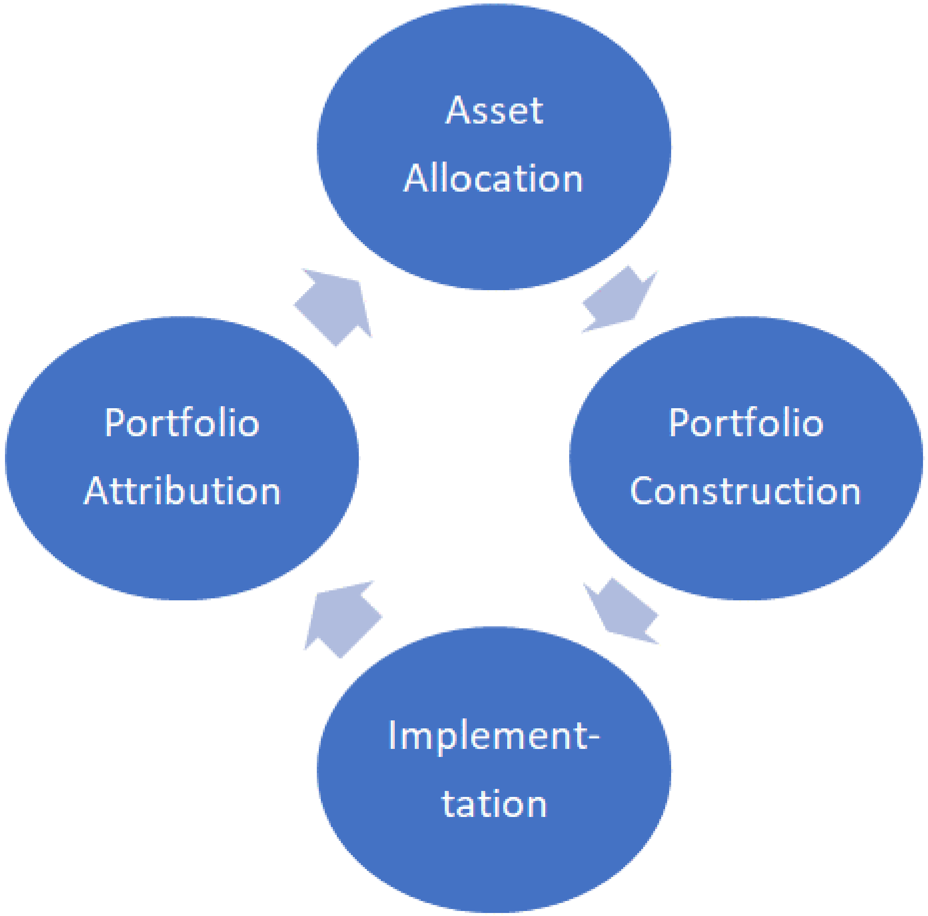
MI = Market Impact Cost
TR = Timing Risk (uncertainty)
λ = Investor’s level of risk aversion

- The solution to the optimization problem will be the optimal time to complete the trade given market impact cost and timing risk, and the investor’s level of risk aversion.



Financial Markets Landscape

Investment Cycle



Asset Classes

Asset Classes

Debt Markets
- Fixed Income
- Money Markets
- Gov't Bonds
- Corporate Bonds
- Municipal Bonds

Equity Markets
- Stocks
- Common
- Preferred
- Indexes
- ETFs

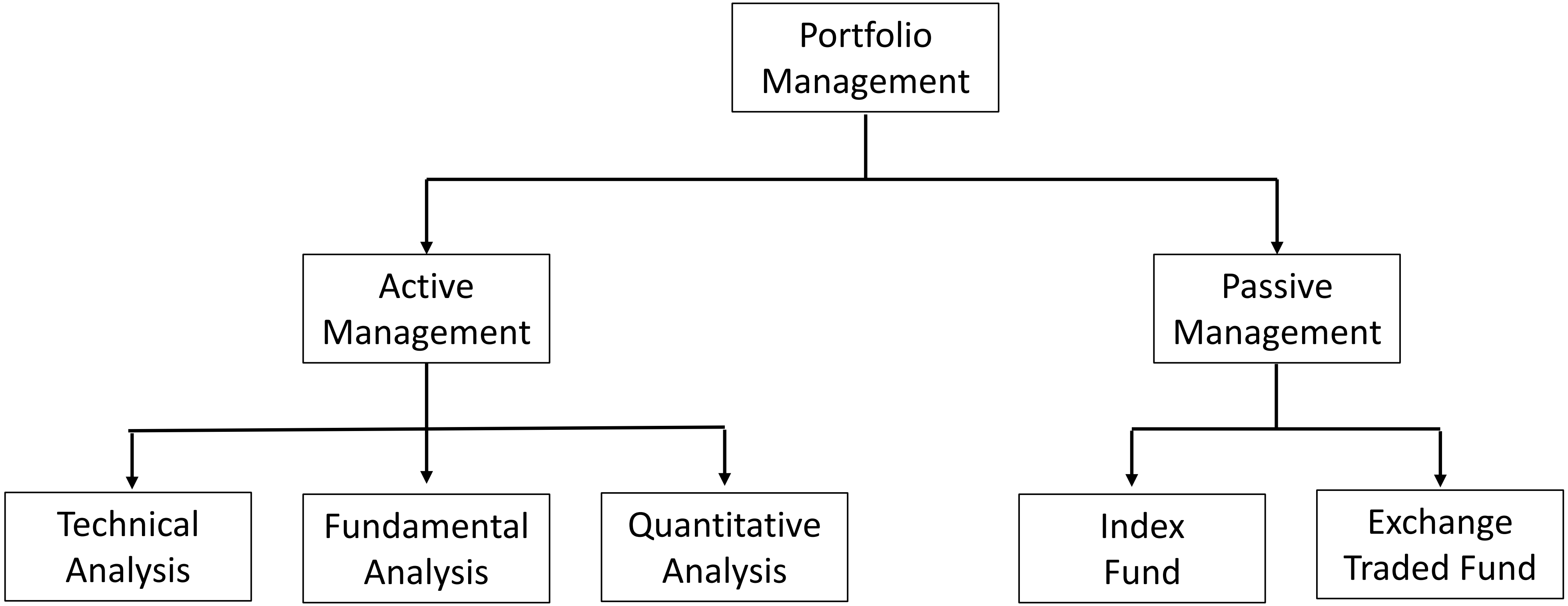
Derivatives Markets
- Options
- Calls & Puts
- Futures
- Forwards
- Swaps

FX Markets
- Exchange Rates
- Foreign Currency
- Hedging

Commodity Markets
- Crops
- Livestock
- Fuels
- Metals

Alternative Investments
- Real Assets
- Private Equity
- Real Estate
- Collectibles
- Sports & Entertainment
- NFTs
- Crypto Coins
- Tokens

Portfolio Management



Portfolio Construction: Investment Motivation

- Cash Inflow
- Cash Redemption
- Income/Dividend Payment
- Short-Term Alpha
- Long-Term Alpha
- Stock Mispricing
- Company Fundamentals
- Quantitative Models
  - Portfolio Optimization
  - Portfolio Rebalance
- Index Change / Reconstitution
- Risk Management
  - Risk Constraints
- Quant Signals
  - Price Target
  - Market Signal
- Statistical Arbitrage
  - Index/ETF-Arb
  - Stat-Arb
  - Risk-Arb/Merger-Arb
  - Pairs-Trade

Old Trading Environment: Before Algorithmic Trading

NYSE	Nasdaq (OTC)
• Specialists • Auction Market • Call Market • NYSE Listed Securities	• Market Makers • Order Market • Quote Driven Market • OTC (Nasdaq) Listed Securities

Old Trading Environment: Before Algorithmic Trading

Listed: A stock listed on the NYSE or AMEX exchanges would trade on these exchanges via a single specialist. The specialist would maintain an order book of bids and asks and was required to maintain an orderly market. Floor brokers wishing to buy and sell in the stock would visit the specialist pit and shout and yell orders to the specialist. The specialist would match the orders with the group of buyers and sellers in front or them and with their book of orders. A listed stock would trade primarily on the exchange on which it was listed.

OTC: A stock that traded via the Nasdaq OTC market via an electronic system of market makers. Depending on the stock, there could be one or multiple market makers. The market makers would each have their own order book of customer asks and bids and would also provide their best bid and ask to the public. Market makers would compete for customer order flow. A Market Maker would typically only publically display their best bid and ask orders to the market. They would not show their full depth of book. (That is, all their sell order they have at a price higher than their best ask and all their buy orders at a price lower than their best bid price.

Electronic Trading Environment: Trade Destinations

Trade Venues

Stock Exchanges

- Traditional Exchange
- Company Listings
- Require Company Financial Filings
- Location to Buy and Sell Stock
- Order Book with Bids and Asks
- Public dissemination of Prices
- Matches Orders
- Maintain fair and orderly market
- Displayed Market

ATS / ECN
Alternative Trading System

- Alternative Trading System (ATS), also know as Electronic Communication Network (ECN)
- Location to Buy and Sell Stock
- Order Book with Bids and Asks
- Public dissemination of Prices
- Matches Orders
- Displayed Market

Dark Pools

- Location to Buy and Sell Stock
- Hidden Order Book with Bids and Asks
- No dissemination of Orders
- No dissemination of Prices
- Matches Orders (e.g., at mid-point of NBBO)
- Trades are printed on Trade Reporting Facility (TRF) and Alternative Display Facility (ADF).

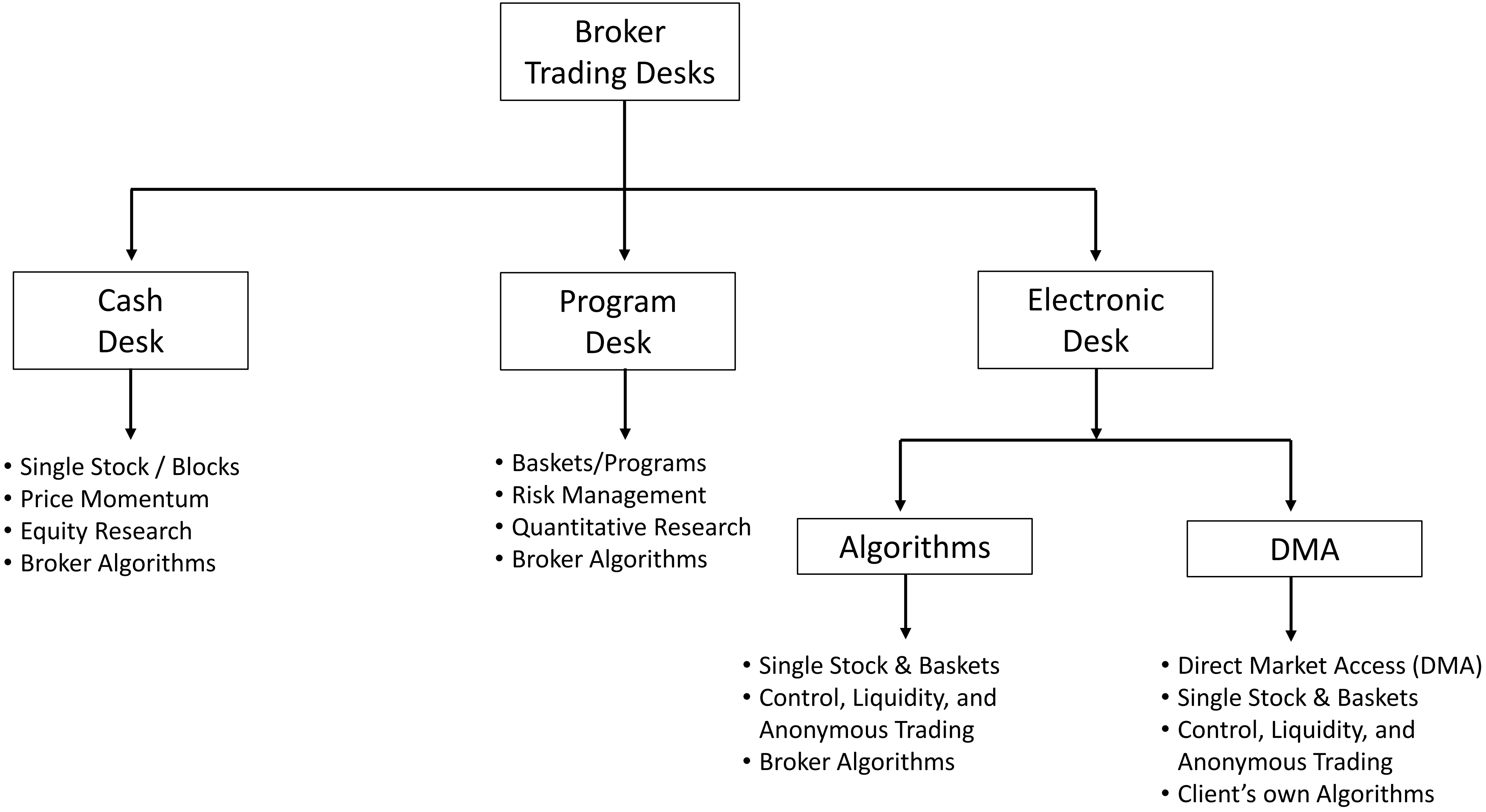
Electronic Trading Environment: Trade Destinations

Exchange: Traditional Exchange where companies list their stock for execution. However, the specialist function has been replaced by a Designated Market Making (DMM) function and the Market-Maker has been replaced by Qualified Market Makers (QMM). An exchange display bids and asks to the public and provide incentives through rebates for providing liquidity to their venue. These new Auto-Market Makers (AMM) are required to maintain quotes for a specified amount of time (as define by the exchanges) in order to qualify for the rebates. Exchanges publicly display their best bid and best ask prices to the market, and clients can view the full depth of book.

Venue (ECN/ATS): A destination where stocks trade like an exchange, however, these venues do not list companies or provide company about the company. Venues originated the rebate revenue model to attract order flow. Venues publicly display their best bid and ask prices to the market. Clients can view the full depth of book of the venue.

Dark Pool (Crossing Network): a dark pool or crossing network is a trading destination that does not publicly display any of their orders or quotes to the public. Their order book is complete hidden to the marketplace. However, due to competition and market regulation, dark pools need to trade at the best available market prices displayed to the public from exchanges or venues or better. The advantage a dark pool is that the customer will often trade within the bid-ask spread and will not disseminate any order information to the marketplace through their transaction.

Implementation: Where do Investors Trade



Broker-Dealer Trading Desks

Function	Cash Desk	Program Desk	Electronic Desk	
			Algorithmic Trading	DMA
Trading:	Single Stock / Blocks	Programs / Baskets Index / ETFs	Single Stocks / Baskets	Single Stocks / Baskets
Trading Concerns:	Price Movement Alpha	Risk Management Cash Balancing	Control / Anonymity Liquidity	Control / Anonymity Liquidity
Primary Research Product	Equity Research	Quantitative Research	Microstructure Research	Microstructure Research
Trade Execution:	Broker Algorithms	Broker Algorithms	Broker Algorithms	Investor Algorithms
Decision Maker:	Cash Trader (w/Investor Instructions)	Program Trader (w/Investor Instructions)	Investor (Client)	Investor (Client)
Sales Team:	Equity Sales Corporate Access	PT Sales Quant Sales	Electronic Sales	Electronic Sales
Commissions	High 1-3 cents/share	Medium 1 cent/share	Low 0.5 - 1 cent per share	Very Low < 0.35 cents per share

Market Participants

Who are the Trading Participants

Trading Participants

Asset Management
- Public Investors
- Institutions
- Money Mangers
- Decision made primarily by Person
- Fundamental and Quantitative Analysis

Hedge Funds
- Private Investors, i.e., "Accredited Investors"
- Quantitative Models
- Decision made by Person and Computer

Proprietary Trading (Prop)
- Private Companies
- Individuals.
- Quantitative & Statistical Models
- Decisions made by Computer using complex mathematical models.

Auto Market Making (AMM)
- Market-Making Firm
- Bids & Asks
- Spread Trading
- Rebate Trading
- Provide Liquidity
- DMM, QMM
- AMM

Retail Traders
- Individuals
- Wealth Managers
- Millennials
- Gen-Z
- Mom & Pop

High Frequency HFT
- Private Companies
- Market-Making
- Profit from Spreads, Rebates & Fees
- Pattern Recognition
- Liquidity Trading

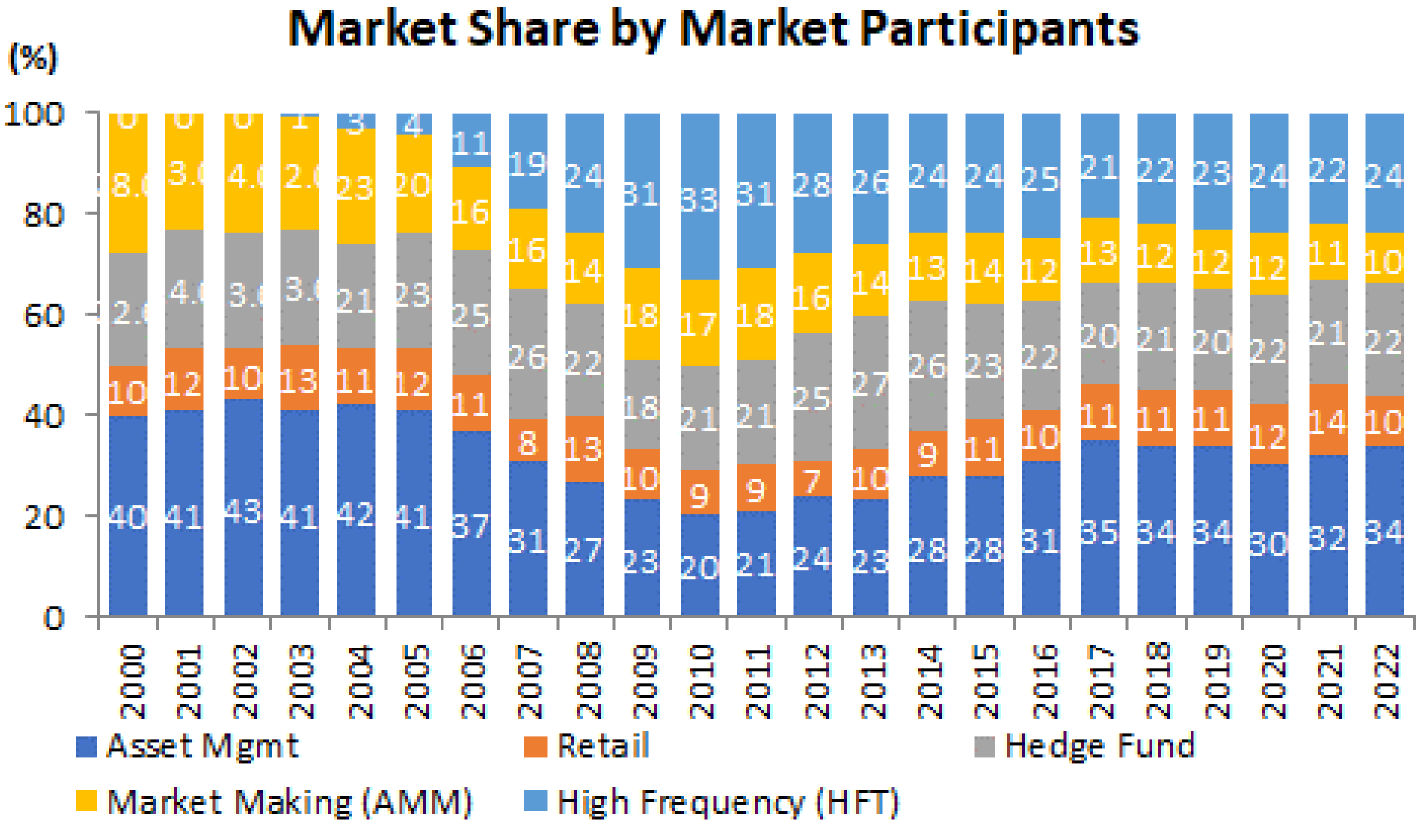
Market Participant Type

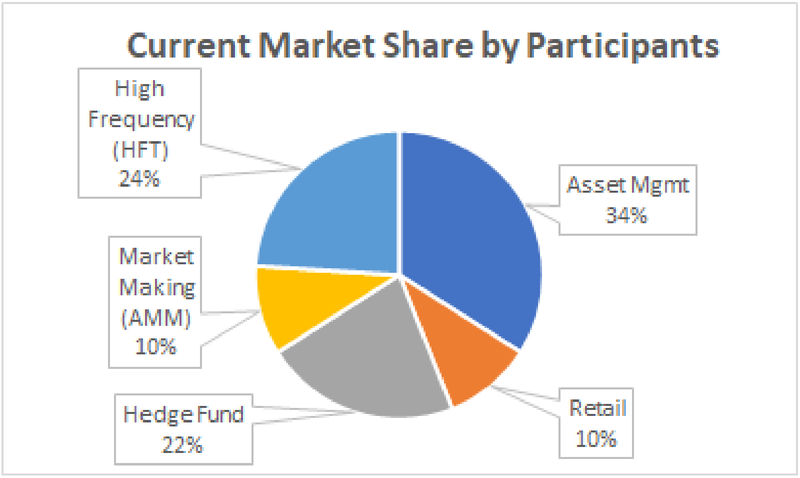
Brokers = Investment Banks, Full-Service, Bulge-Bracket, Research Brokers, etc. These are the market participants who facilitate the trade.

Participants

- Asset Management = Institutions, Mutual Fund, Index Fund, Insurance Companies
- Hedge Funds = Quant & Non-Quant
- Market Makers = Liquidity Providers, Specialist / Market Makers, NYSE-DMM, Nasdaq-QMM, AMM-Brokers
- Retail Investors = Individuals, Wealth Managers, Millennials, Gen-Z
- Proprietary Trading Firms (Prop) = Prop Firms. Categorized as Hedge Funds, Liquidity Providers, and/or HFT Firms.
- High Frequency Trader (HFT)

Market Participants





Source: Kissell Research Group (2022)

Trading Algorithms

Types of Algorithms

- **Execution-Only** = Algorithms are tasked with transacting an order that was entered by a portfolio manager and determined outside of the system. Investors specify the transaction rules to the algorithm at beginning of trading.
- **Quantitative-Algos** = Algorithms that are tasked with making the investment decision and then transacting the order in the market to earn a profit. These algos are also often referred to as "Profit-Seeking" algos. The investment decision is often based on a quantitative approach such as portfolio optimization, mathematical model, or stat-arb approach. Quantitative algorithms make investment decisions based on a mathematical model and seek to earn an investment profit. Once an investment opportunity is uncovered in the market the algorithm will immediately execute that decision in a manner appropriate for the investment opportunity. These algorithms seek to profit from their investments and are used by quantitative traders and proprietary trading firms.
- **Liquidity-Providers** = Algorithms that provide liquidity to the market though entering bids (buy orders) and asks (sell orders) to trade venues and seek to earn a "trading profit" (e.g., profiting through short-term buying and selling of stocks based on investor demand. These algorithms will earn a profit via three means: i) profit from the bid-ask spread by buying at the bid (lower price) and selling at the ask (higher price), ii) via market rebates where trade venues provide a rebate (monetary incentive or reward) to investors who provide liquidity to that venue, and iii) by uncovering buying and/or selling patterns in the stock and using that information to their advantage.

Special Types of Algorithms

- **Auto Market Making (AMM)** = Algorithms tasked with performing the traditional specialist and market-making function of providing liquidity in the stock via bids and offers. E.g., NYSE = DMM and Nasdaq = QMM. AMM algorithms seek to profit off the bid-ask spread and from rebate incentives provided by the exchange for providing liquidity. Brokers and high frequency traders (HFT) will also engage in auto market making (AMM) activities. Exchange AMM firms have certain obligations regarding posting orders and will need to provide liquidity via orders a specified percent of time.
- **Direct Market Access (DMA) =** Brokers provide investors with connectivity and market access to the various trading venues. Clients use these connections but employ their own algorithms to transact their order instead of using broker algorithms. DMA allows investors to customize their execution strategy for their specific investment decision.
- **High Frequency Trading (HFT)** = Traders who engage in liquidity trading to earn a trading profit. HFT algorithms do not have any obligation to provide liquidity to the market and will only post orders when they feel they will profit. HFT algorithms are notorious for seeking to uncover investor and/or market buying and selling trends to use this information to their advantage. Once they acquire a position (long or short) they immediately seek to offset these shares at a profit via using all market venues and dark pools.

High Frequency Trading (HFT)

- Liquidity Provider / Liquidity Trading
- Auto Market-Making (AMM)
- Spread Trading – Bids and Asks
- Fees & Rebates
- Seek to uncovering Investor Trading Patterns - using publicly available market data (prices and quotes) and information.
- Use of all trading venues including Exchanges, ATS, and Dark Pools

Algorithm Urgency

- **Aggressive:** Get Me Done. Sweep all Liquidity available at My Price or Better. Uses more market orders during times of favorable prices to capture these better prices.
- **Working Orders:** Balance the tradeoff between cost and risk, manage placement of market and limit orders. VWAP/TWAP, POV, Implementation Shortfall, Inline.
- **Passive:** Usage of crossing systems and dark pools. Liquidity Seeking Algorithms. Will use more limit orders than market orders.

Algorithm Slicing Strategies

- **Time-Based:** Trade a specified number of shares at specified times during the day. E.g., execute 10% of the order between 9:30am and 10:00pm.The same number of shares will occur in these time periods regardless of market volumes and market prices.
- **Volume-Based:** Participate with a specified amount of volume. E.g., POV=10% indicates that your trades will constitute 10% of market volume. More trading will occur in times of higher market volume and less trading will occur in times of lower market volume.
- **Price-Based:** Traders may execute more or less aggressively based on market prices.

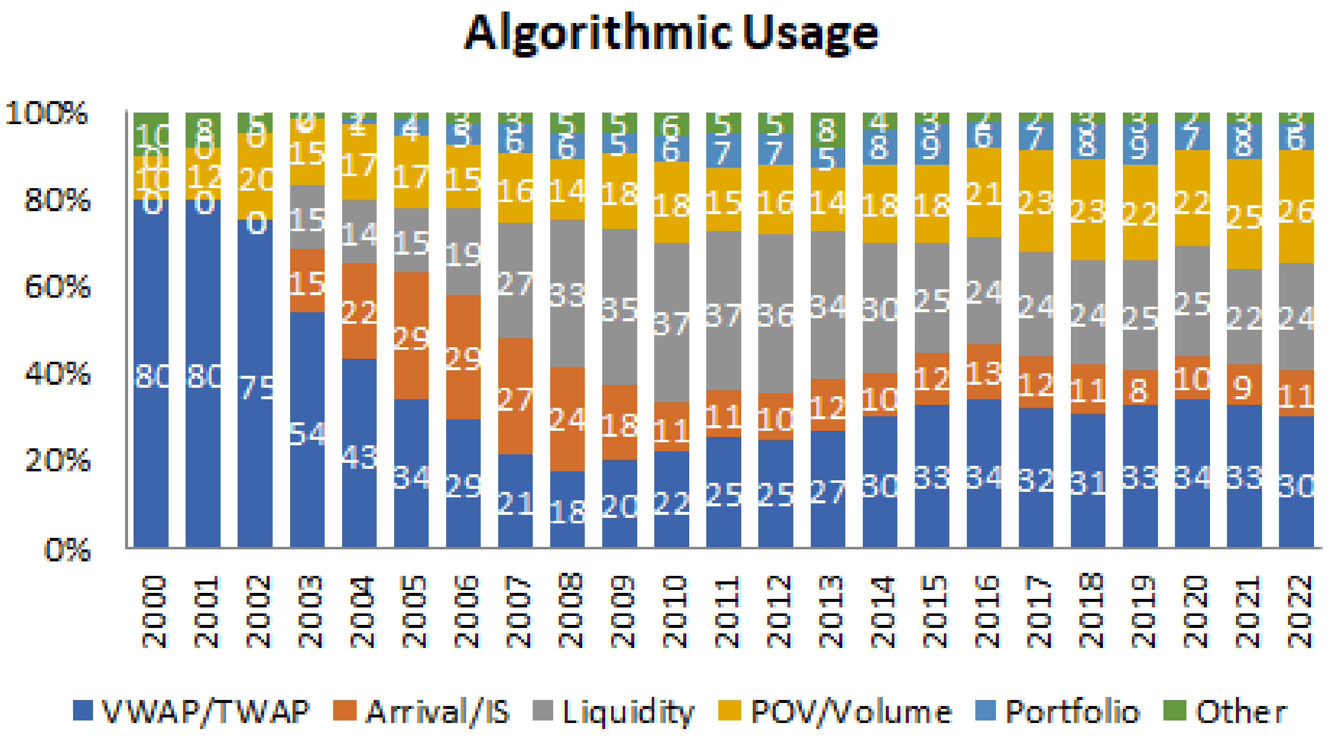
Algorithm Updating

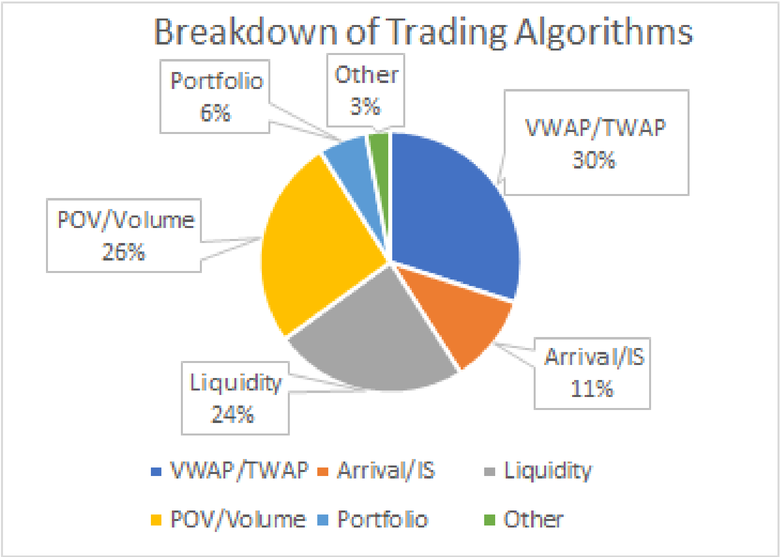
- **Static**: An algorithm that does not update, revise, change, or modify its trading strategy during the execution of the order. Once the parameters for these algorithms are specified, they can only be changed by the trader making a manual revision to the algorithm.
- **Dynamic**: An algorithm that revises its trading strategy and parameters during execution of the order based on changing and unexpected market conditions. These revisions are made by the algorithms itself and is often based on a specified mathematical equation or real-time optimization that considers market conditions, future expectations, and realized prices.

Algorithm Types

- VWAP / TWAP
- POV / Volume
- Arrival Price / Implementation Shortfall (IS)
- Liquidity Seeking / Dark Pool Algorithms
- Front-Load / Back Load
- MOO / MOC
- Optimal Strategy
- Portfolio / Basket Algorithms
- Dynamic

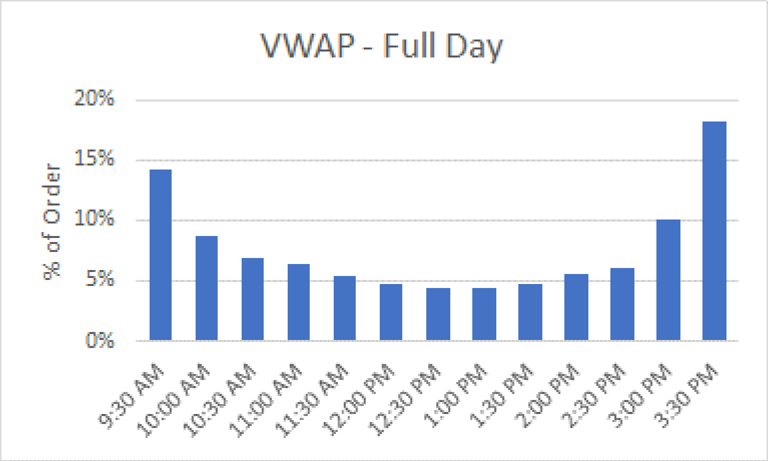
Trading Algorithms

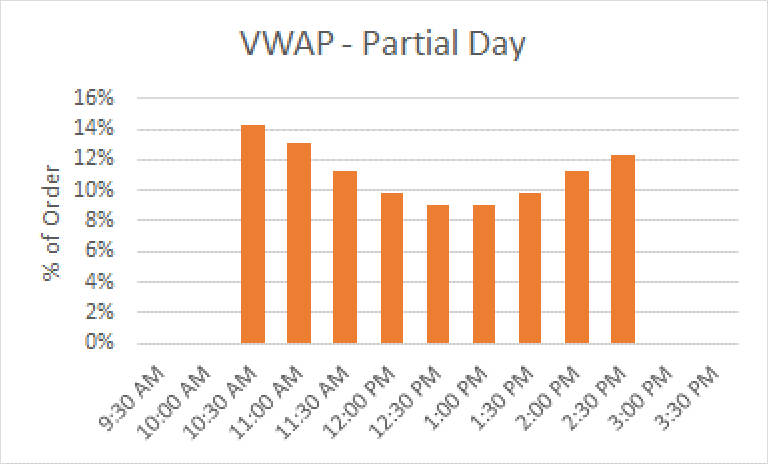




Source: Kissell Research Group (2022)

VWAP Algorithms





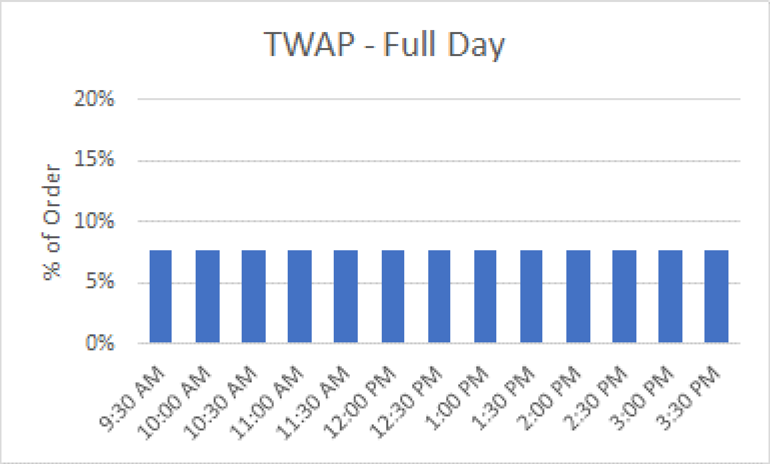
- A VWAP algorithm, e.g., Volume Weighted Average Price, is an algorithm that slices the order over the day or over a specified trading period based on the intraday volume profile of the stock. Historically, there has always been more volume traded at the open and close than during midday hours. More recently, there is even a greater amount of volume traded at the close than at the open.

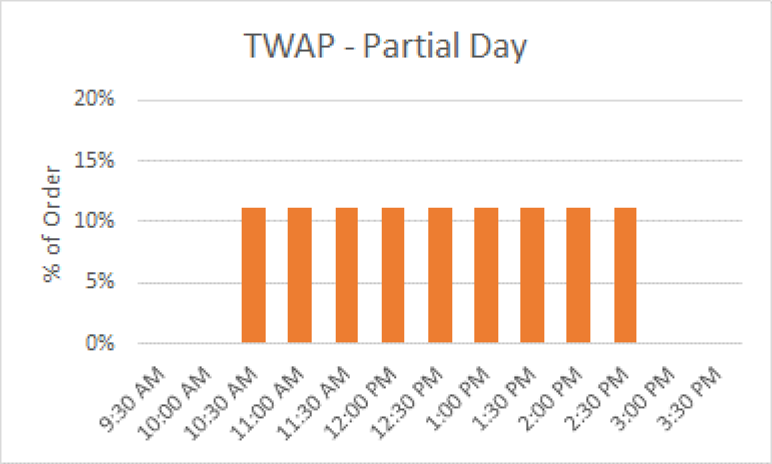
- The graph on the top left illustrates a full-day VWAP algorithm. Notice how the algorithm adapts to different trading patterns throughout the day.

- The graph in the bottom left illustrates how a VWAP algorithm would trade during a partial day, e.g., from 10:30am through 2:30pm. Notice how this algorithms adheres to the intraday volume profile of the stock during the trading period.

Source: Kissell Research Group (2022)

TWAP Algorithms





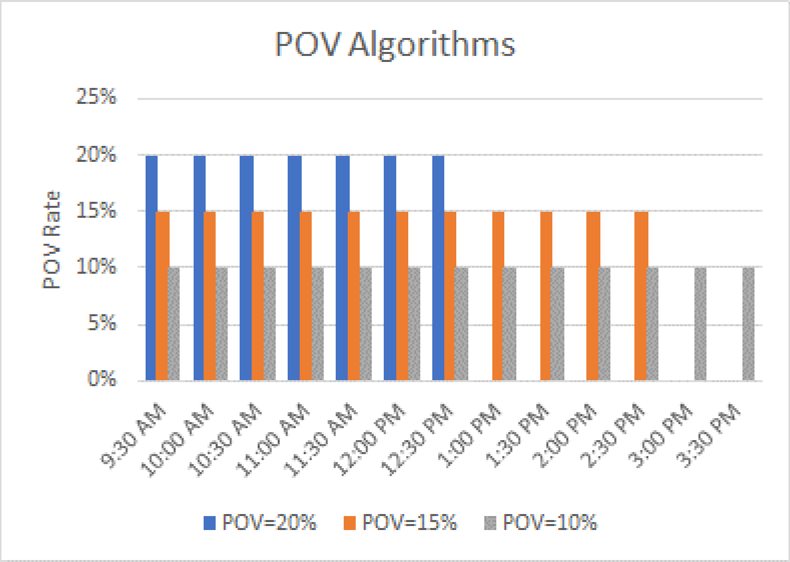
- A TWAP algorithm, e.g., Time Weighted Average Price, is an algorithm that slices the order over the day or over a specified time period using equal share quantity amounts in each period. In statistics, this type of slicing is often described as a uniform distribution.

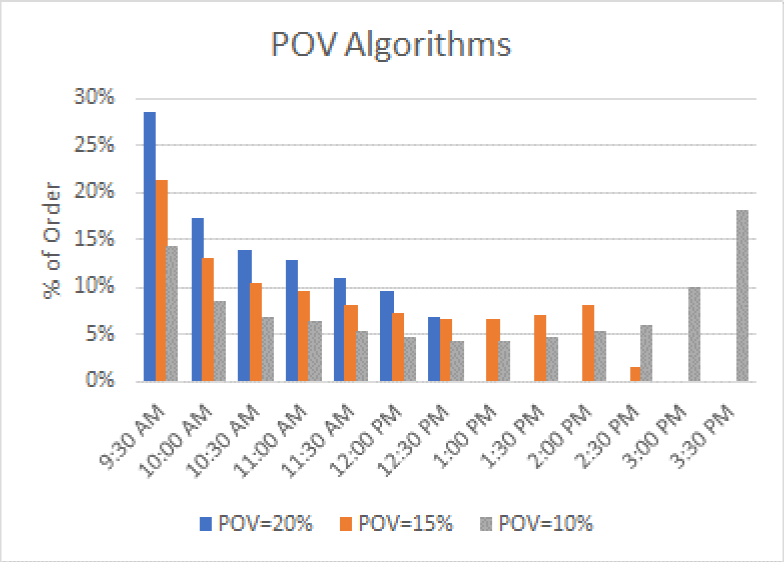
- The graph on the top left illustrates a full-day TWAP algorithm. Notice how the TWAP algorithm trades the same percentage of the order in each trading period.

- The graph in the bottom left illustrates how a TWAP algorithm would trade during a partial day, e.g., from 10:30am through 2:30pm. Notice how this algorithms trades the same quantity of shares in each trading period. It does not make any changes based on different intraday volume profiles.

Source: Kissell Research Group (2022)

POV Algorithms





- A POV algorithm, also known as a “percentage-of-volume,” “volume-participation,” “volume-follow,” or simple a “volume-based” algorithm is an algorithm that trades at a constant percentage of volume in each period until the order is completed.

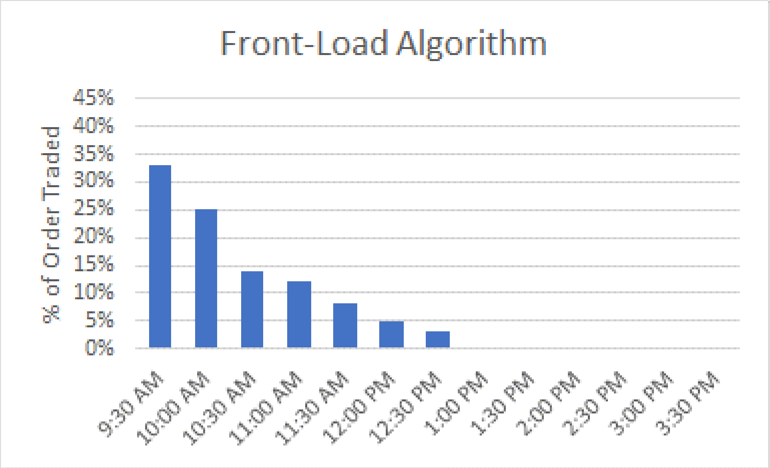
- For example, POV=10% indicates that the algorithm is to participate with 10% of the market volume. This means that whenever 1000 shares trades in the market the investor will need to have transacted 100 shares.

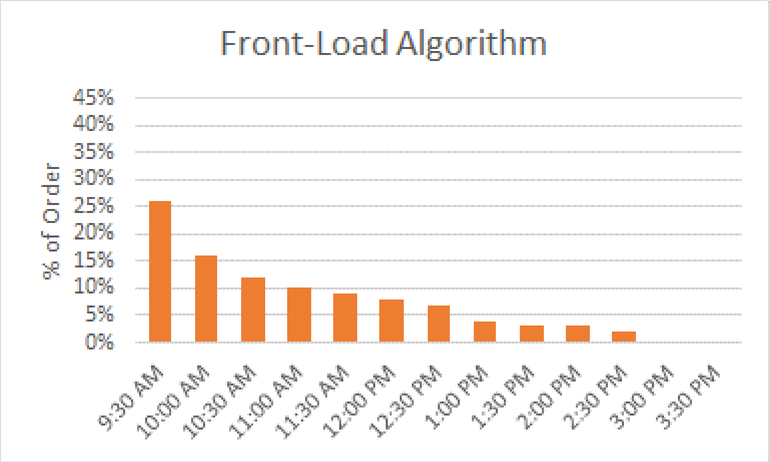
- The graph on the upper left shows the POV rate (percentage of volume trading trade) for three different stocks. Orders with a higher POV rate will complete sooner than orders with a lower POV rate.

- The graph on the bottom left shows the % of the order that is expected to be transacted in each period. Notice how a constant POV results in different number of shares being transacted in each period. This is because stocks trade different amounts in each period during the day.

Source: Kissell Research Group (2022)

Front-Load Trading Algorithms

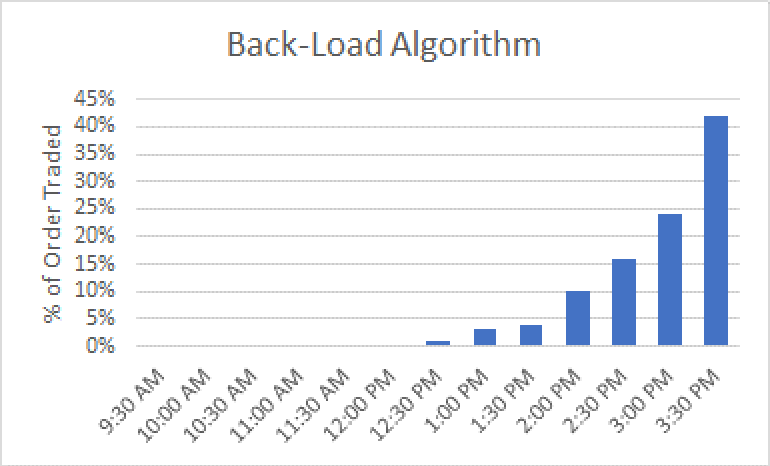


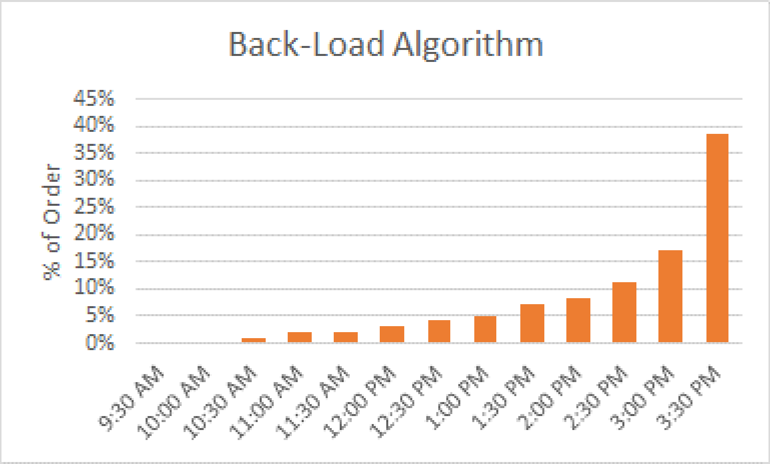


- **Front-Load.** A front-load algorithm is time-slicing algorithm that trades more aggressive at the beginning of the order and more passive at the end of the order.
- A front-load algorithm is often used by investors who are trying to capture prices as close to the arrival price as possible and still want to manage the trade-off between trading costs and timing risk.
- The graph in the upper left shows an example of an aggressive front-load algorithm. Notice that this algorithm is expected to complete the order by early afternoon.
- The graph in the lower left shows an example of a passive front-load algorithm. Notice that this algorithm is expected to complete the order by late afternoon just before the close.

Source: Kissell Research Group (2022)

Back-Load Trading Algorithms





Source: Kissell Research Group (2022)

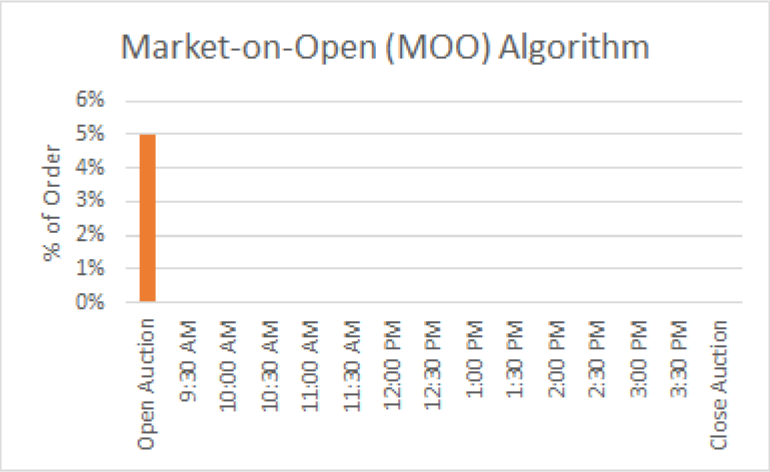
- **Back-Load.** A back-load algorithm is a time-slicing algorithm that trades more passive at the beginning of the order and more aggressive at the end of the order.

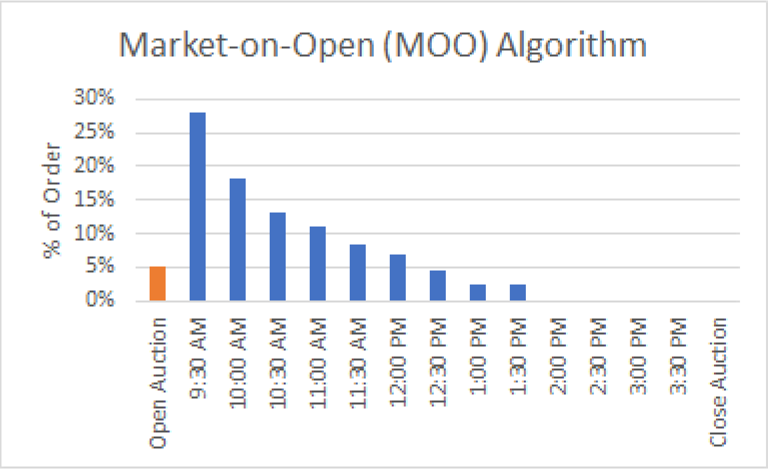
- A back-load algorithm is often used by investors who are trying to capture prices as close as possible to a future benchmark price, such as the close, and still want to manage the trade-off between trading cost and timing risk.

- The graph in the upper left illustrates a more aggressive back-load strategy. This strategy begins trading in the early afternoon with completion at the close.

- The graph in the lower left illustrates a more passive back-load algorithm. This strategy begins passively trading in mid-morning and gradually increases its trading into the close.

Market-on-Open (MOO) Algorithms





Source: Kissell Research Group (2022)

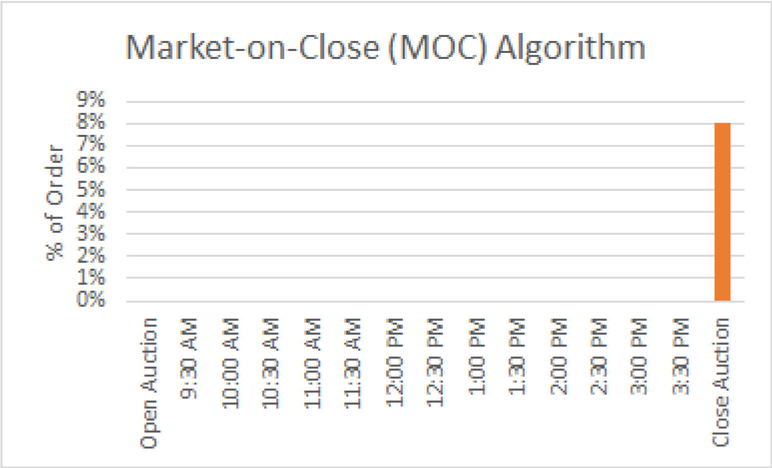
- A Market-on-Open (MOO) algorithm is an algorithm that will only enter shares into the opening auction of the exchange for execution at the official opening price on the day. Opening auction orders will receive the official opening price on the day (which is not know in advance).

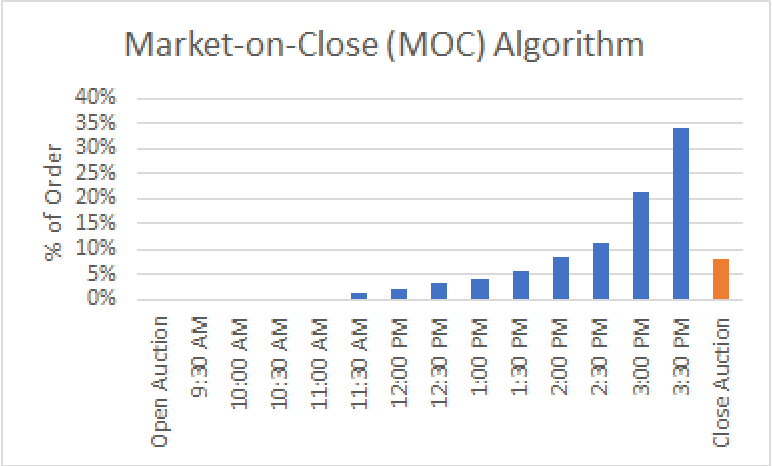
- An MOO algorithms is often used in conjunction with other Algorithms. Especially when the order is too large to transact in only the opening auction

- The graph in the upper left shows an example of a MOO algorithm. Notice how this algorithm will only participate in the opening auction.

- The graph in the lower left shows an example of a front-load strategy coupled with an MOO order. Notice this algorithm will trade in the opening auction as well as through the day following the specified slicing strategy of the front-load strategy.

Market-on-Close Algorithms

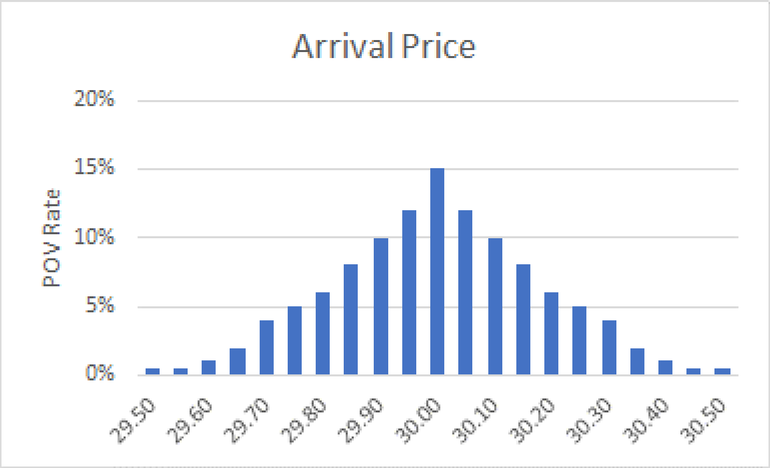


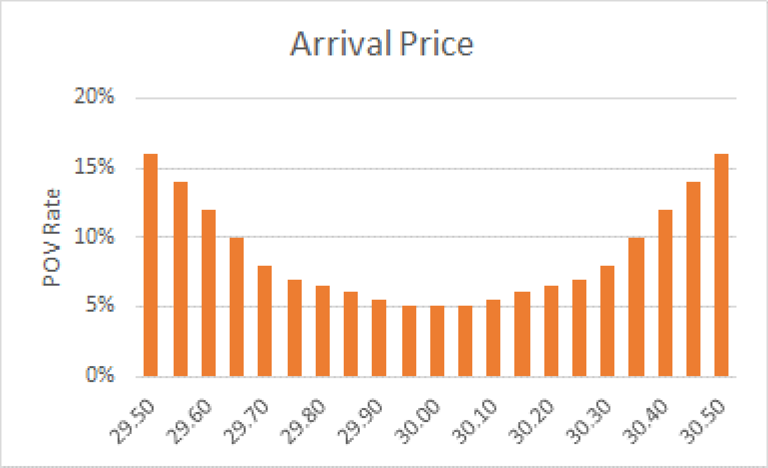


Source: Kissell Research Group (2022)

- A Market-on-Close (MOC) algorithm is an algorithm that will only enter shares into the closing auction of the exchange for execution at the official closing price on the day. Closing auctions require shares to be entered for execution prior to the close. Investors utilizing MOC algorithms are guaranteed to have all shares executed at the closing price but will not know the exact transaction price until after the market closes.
- At many venues, once order is entered into the closing auction after a specified time, the order is guaranteed to be executed but the order cannot be cancelled once entered. MOC algorithms are often used in conjunction with other algorithms when the order is too large to execute solely in the closing auction.
- The graph on the upper left is an example of a MOC algorithm. Notice how this strategy only calls for shares to be traded in the closing auction.
- The graph on the lower left is an example of a back-load algorithm coupled with a MOC order. Notice how this strategy trades during the day as well as a specified number of shares at the close.

Arrival Price Trading Algorithms

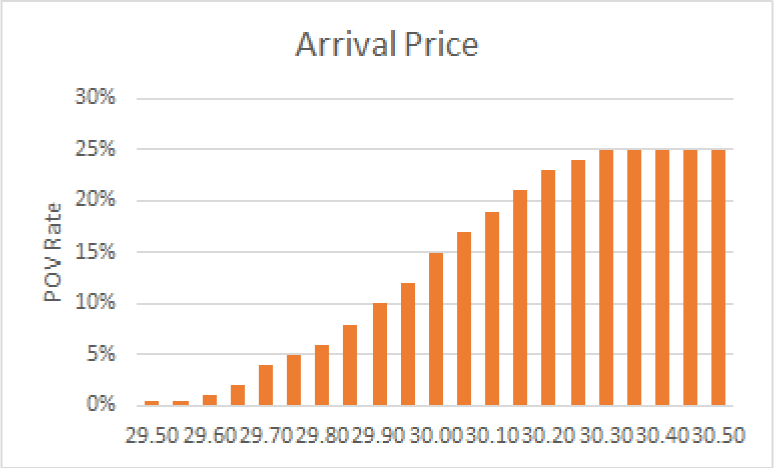




Source: Kissell Research Group (2022)

- An “Arrival Price” algorithm, also often referred to as an “Implementation Shortfall” algorithm is an algorithm that varies its trading rate based on market prices.
- An arrival price algorithm may trade aggressive (faster) or passive (slower) when market prices are at or near the arrival price of the order. As market prices move further away from the arrival price, either higher or lower, the arrival price algorithm will change its trading rate.
- It is important to mention that the trading behavior of Arrival Price algorithms are not consistent across brokers and vendors, and it is important for investors to understand exactly how the specific arrival price algorithm will transact shares in the market.
- The graph in the upper left is an example of an arrival price algorithm that trades more aggressively when prices are at or near to the arrival price and more passive when prices change (become higher or lower).
- The graph in the lower left shows an arrival price algorithm that behaves in the opposite manner. This algorithm is more passive when prices are at or near the arrival price and then becomes more aggressive as prices become higher or lower.
- Arrival price algorithms are often coupled with dynamic behavior.

Arrival Price Trading Algorithms



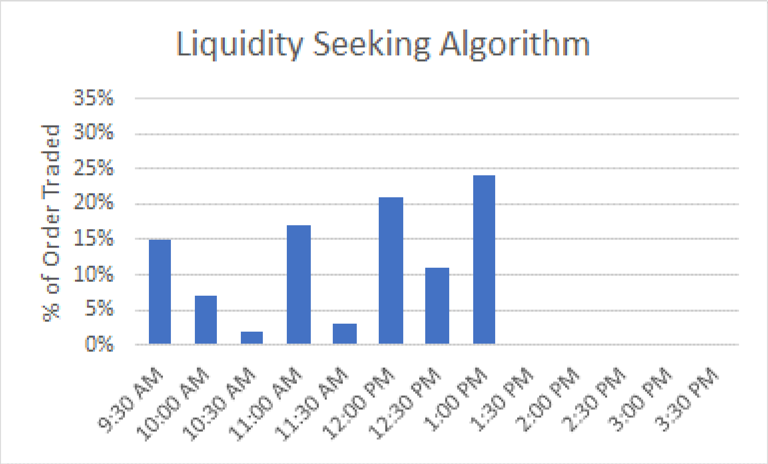
Source: Kissell Research Group (2022)

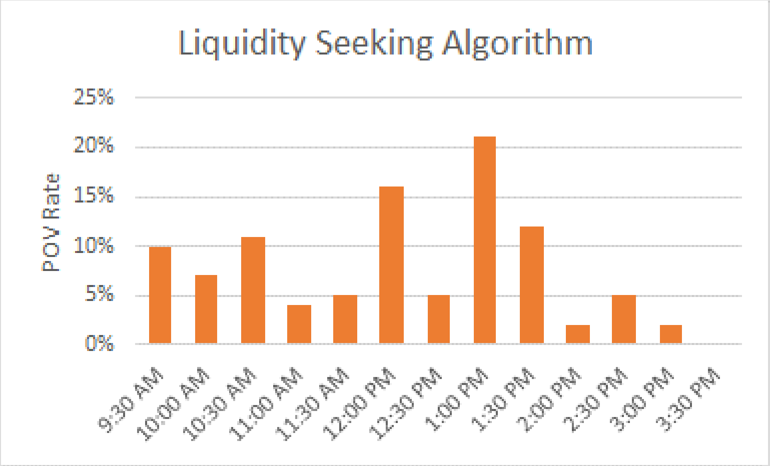
- The graph in the upper left is another example of an Arrival Price algorithm. Notice how this algorithm will trade faster (higher POV rate) as prices below lower and will trade slower (lower POV rate) as prices become higher.

- The graph in the lower left is another example of an Arrival Price algorithm with the opposite behavior. Notice how this algorithm will trade slower (lower POV rate) as prices below lower and will trade faster (higher POV rate) as prices become higher.

- These types of Arrival Price algorithms are often specified by investors who expect stocks to exhibit trending behavior.

Liquidity Seeking Algorithms

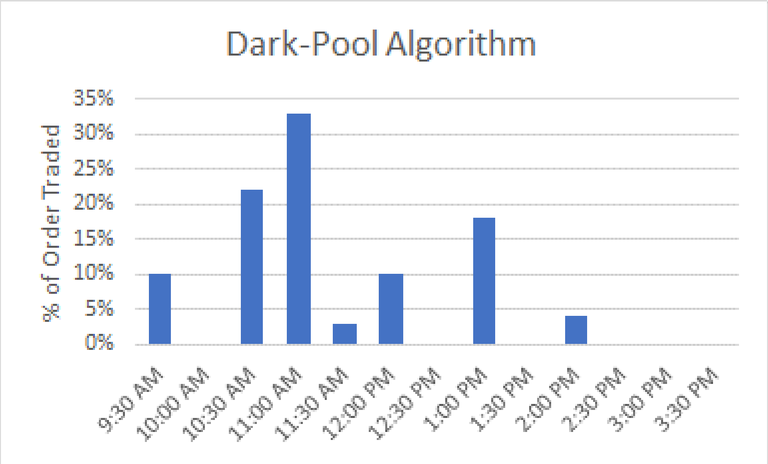


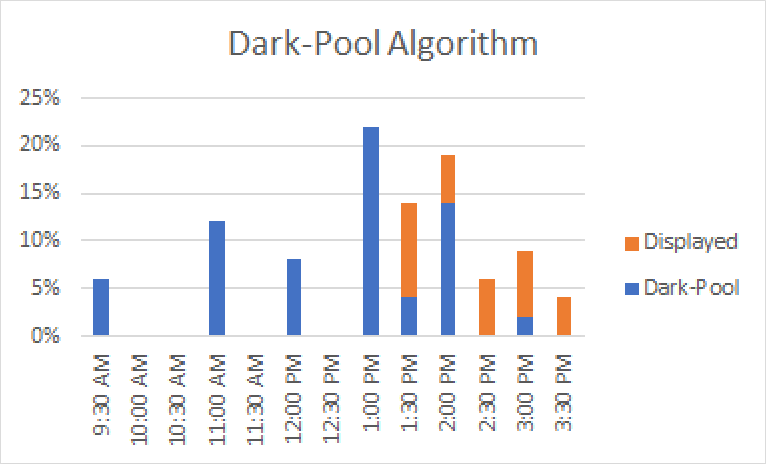


- **Liquidity Seeking.** A liquidity seeking algorithm is an algorithm that will utilize all trading venues (displayed and dark venues) to capture liquidity at a specified price or better. The liquidity seeking algorithm will often trade in an aggressive manner to capture as much liquidity as possible during times of favorable prices. The liquidity seeking algorithm will also make appropriate use of limit orders and dark pools.
- A liquidity seeking algorithm is also used by investors to execute shares at the tail end of the order. For example, trade aggressively to complete the order. In this situation, investors are not as concerned with information leakage if they can complete the order.
- Investors can also often specify how much to trade in a dark pool compared to the displayed venues.
- The graph in the upper left shows an example of a liquidity seeking algorithm that was able to transact at its specified price and complete the order by early afternoon.
- The graph in the lower left shows an example of a liquidity seeking algorithm that is not able to locate appropriate liquidity and requires a longer period to complete the order.

Source: Kissell Research Group (2022)

Dark Pool Algorithms





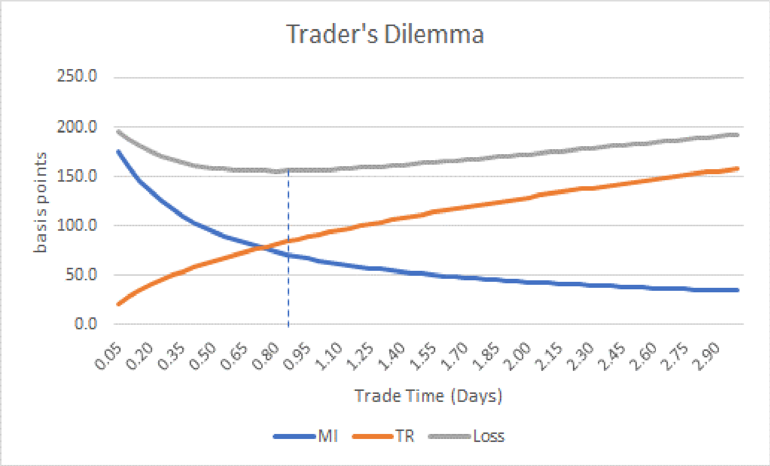
Source: Kissell Research Group (2022)

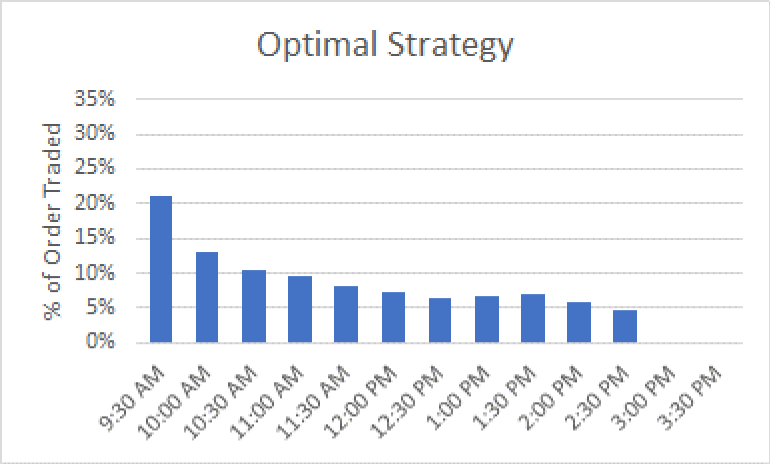
- **Dark-Pool.** A dark pool algorithm is an algorithm that will only execute shares in the numerous industry dark pools. Investor utilize dark pool algorithms when they wish to remain anonymous and do not want to convey any information to the market regarding their trading intentions. Dark-pool algorithms are often used for large orders.

- The graph in the upper left shows an example of a dark-pool algorithm. In this example, the algorithm is able to find required liquidity in dark pools and complete the order by mid afternoon. Notice, however, that dark-pool algorithms may not find ample liquidity and may have periods without any transactions.

- The graph in the lower left shows an example of a dark-pool algorithm that is not having luck finding required liquidity to complete the order. In these situations, the dark-pool algorithm may solicit trades from the displayed markets. Clients will need to specify how the dark-pool algorithm is to behave in situations where the order may not be completed. Some clients will elect to transact in the displayed venues while some may elect to not complete the order if there is not sufficient liquidity in the dark pools.

Optimal Strategy Algorithm





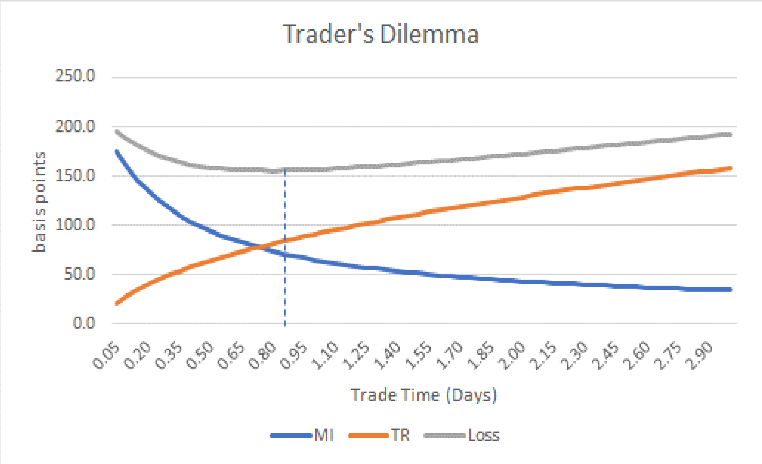
Source: Kissell Research Group (2022)

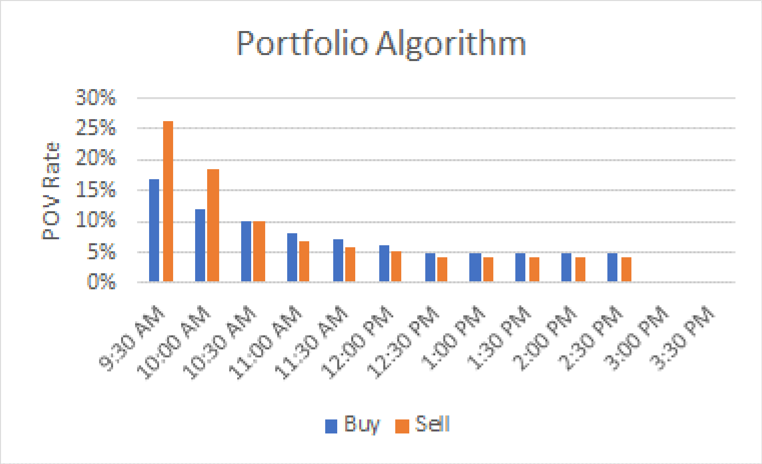
- **Optimal Strategy.** An optimal strategy algorithm is an algorithm whose execution strategy (e.g., POV rate) is determined through an optimization process. For example, a common optimization specification is to solve the trader's dilemma where investors seek to balance the trade off between market impact and timing risk for a specified level of risk aversion.

- The graph in the upper left shows an example of how the optimizer will solve the trader's dilemma for a single stock Notice how market impact cost decreases by trading over a longer period of time but timing risk (which is market exposure risk) increases when we trade slower. The optimizer will find the best solution for the investor based on their level of risk aversion.

- The graph in the lower left shows the actual trade schedule resulting from the optimization process and how many shares of the order to execute in each time period.

Portfolio / Basket Algorithms

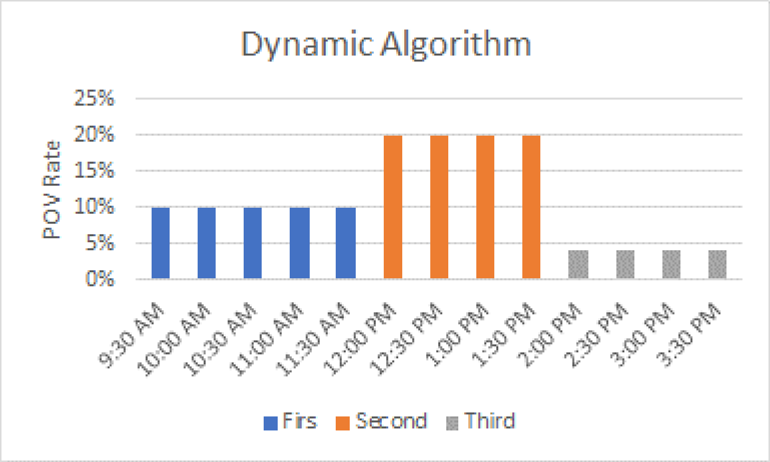


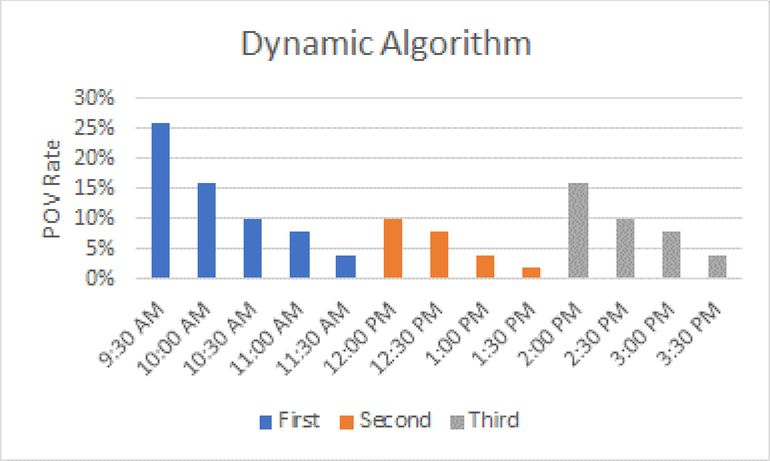


Source: Kissell Research Group (2022)

- **Portfolio Algorithm / Basket Algorithm.** A Portfolio Algorithm (also referred to as a Basket Algorithm as well as Portfolio IS) is an algorithm that transacts a basket of stock consisting of one-sided orders such as all buy or all sell orders, or a two-sided order that consists of both buy and sell orders.
- A portfolio algorithm determines the appropriate execution strategy using an optimization process based on make on the overall cost and risk of the basket and the investor's specified level of risk aversion. A higher risk aversion will result a faster execution, higher market impact cost, and lower risk. A lower risk aversion will result in slower execution, lower market impact, and higher risk. Portfolio algorithms make decisions based on the overall trade list characteristics and costs and not at the individual stock level.
- The graph in the upper left shows an example of how the optimizer will determine the appropriate strategy based on the tradeoff between market impact cost and timing risk at a specified level of risk aversion. As mentioned, in this situation, the optimizer is considering the cost and risk of the aggregated trade list.
- The graph in the lower left shows an example of the solution for a two-sided basket with higher risk coming from the sell orders. Notice how the optimizer executes more of the sell orders in the beginning of the days which results in equal risk from buy orders and sell orders afterwards. In this case, the trade list is then well hedged to potential market movement.

Dynamic Algorithms





Source: Kissell Research Group (2022)

- **Dynamic.** A dynamic trading algorithm is an algorithm that adapts to changing market conditions such as prices and volumes based on investor specified trading rules and risk aversion specifications.
- These rules allow the algorithms to take advantage of market conditions and realized prices when appropriate.
- Algorithms can make often dramatic changes to the current trading rate. This is usually accomplished via a specified set of rules or equations, or via a re-optimization process.
- Dynamic trading logic is also often integrated into the algorithms mentioned above.
- The graph in the upper left shows the specified POV rate for a stock with dynamic optimization. In this example, the algorithm underwent three optimizations resulting in three different POV rates.
- The graph in the lower left shows the shares that well be executed in the market based on these optimal POV rates and actual market volumes and conditions.

Execution Style

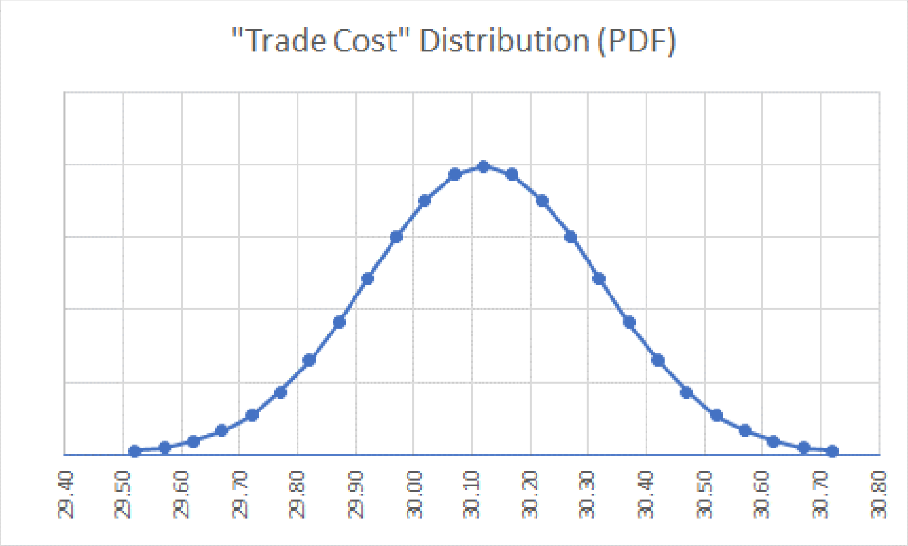
Trading Types

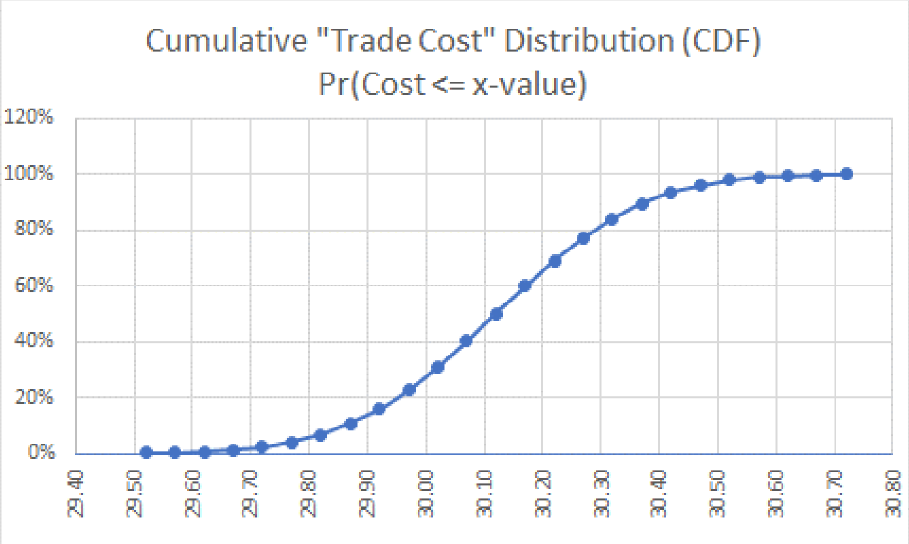
- **Agency Execution:** the investor/fund pays the broker a “commission” to execute the order on a “best efforts” basis. Prices are unknown in advance and the investor incurs all market risk. If the prices increase a buy order will execute less favorably, and if it the prices decrease the buy order will execute more favorably. Vice versa for sell orders. In an agency transaction the broker profits the commission. Commissions are 1-3 cents per share.

- **Principal Bid / Capital Commitment:** the investor pays the broker a “premium” to execute the order. This premium amount is also known as a block bid, principal bid, or risk bid. In a principal bid, the investor receives a known or guaranteed price (e.g., current price, closing price, VWAP price) and transfers all risk to the broker. The principal broker receives the order increasing or decreasing their inventory position. If they can offset the acquired order (position) at a cost less than the bid amount they received they will profit, if not they will incur a loss. Brokers will always seek to hedge their risk in a principal bid transaction.
    - Principal Bid is much higher, say 5-25 cents per share.

Agency Execution: Example

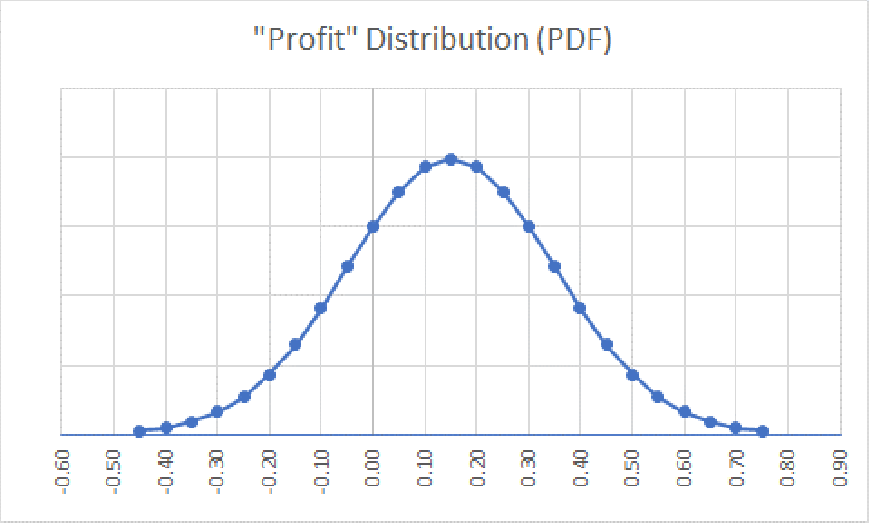
- **Example:**
- An Investor wishes to buy 100,000 shares of stock RLK using an agency execution.
- The current price of RLK is Price=$30.00. The market impact cost for the trade is MI=$0.10 and timing risk is TR=$0.20. The broker charges a commission of Comm=$0.02/share.
- The expected execution price for RLK using an agency transaction including the commission is:
- My All in Price Price = $30.00 + $0.10 + $0.02 = $30.12
- The standard deviation of the expected execution price is:
- TR = $0.20.
- Therefore, the expected execution price is:
- $30.12 +/- $0.20.
- The potential set of possible execution prices is illustrated in the Trade Cost PDF and CDF graphs.

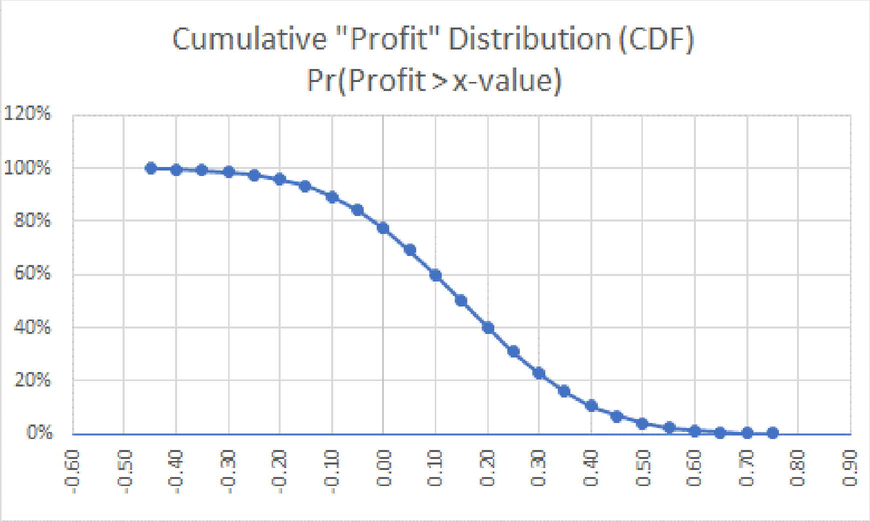




Principal Bid Transaction: Example

- **Example:**
- An Investor wishes to buy 100,000 shares of stock RLK using a principal bid transaction.
- The current price of RLK is Price=$30.00. The broker charges the investor a principal bid of $0.25/share for this transaction.
- In this situation, the investor receives an execution price of $30.00 but pays the broker the bid amount of $0.25. There is no risk for the investor. All risk is transferred to the broker. My all in Price $30.25.
- The broker will need to purchase 100,000 shares in the market. The market impact cost for the trade is MI=$0.10 and timing risk is TR=$0.20.
- The expected profit for the broker is:
- Profit = Bid – MI Cost = $0.25 - $0.10 = $0.15 with TR = $0.20.
- The broker has a 78% chance of earning a Profit.
- The broker's potential Profit distribution is illustrated in the Trade Cost PDF and CDF graphs.





Market Order Book

Order Types

- **Market Order** = an order to immediately buy or sell stock at the best available market price.
- **Limit Order** = an order to buy or sell stock at a specified price or better.
- **Bid Price** = a buy order. This is the price that an investor wishes to pay for stock. i.e., the buyer is bidding a specified amount to buy shares.
- **Ask Price** = a sell order. This is the price that an investor wishes to sell shares. i.e., the seller is asking other investors to pay the specified value for shares. Also referred to as the Offer price. The price at which an investor is offering the stock.
- **Bid-Ask Spread** = the difference between the best bid and ask price. It represents the total cost of trading if an investor were to simultaneously buy and sell shares in the same stock. Also referred to as simply the Spread.
- **Order Book** = the collection of all bids and asks at a trade venue.

Order Book – Single Venue

Order Book - Single Venue

Quote: Bid - Ask
$30.00 - $30.10
$30.00 x 800 - $30.10 x 300

Buy Orders (Bids)

Time	Price	Shares
10:00 AM	30.00	100
10:05 AM	30.00	500
10:15 AM	30.00	200
10:00 AM	29.90	500
10:20 AM	29.90	100
10:10 AM	29.80	500
10:15 AM	29.80	1000

Sell Orders (Asks)

Time	Price	Shares
10:00 AM	30.10	100
10:20 AM	30.10	200
10:00 AM	30.15	500
10:10 AM	30.15	100
10:20 AM	30.15	1000
10:00 AM	30.20	500

Execution Priority: Order Queue

Price-Time

Buy Orders (Bids)

Time	Price	Shares
10:00 AM	30.00	100
10:05 AM	30.00	500
10:15 AM	30.00	200
10:00 AM	29.90	500
10:20 AM	29.90	100
10:10 AM	29.80	500
10:15 AM	29.80	1000

Sell Orders (Asks)

Time	Price	Shares
10:00 AM	30.10	100
10:20 AM	30.10	200
10:00 AM	30.15	500
10:10 AM	30.15	100
10:20 AM	30.15	1000
10:00 AM	30.20	500

Price-Size

Buy Orders (Bids)

Time	Price	Shares
10:05 AM	30.00	500
10:15 AM	30.00	200
10:00 AM	30.00	100
10:00 AM	29.90	500
10:20 AM	29.90	100
10:15 AM	29.80	1000
10:10 AM	29.80	500

Sell Orders (Asks)

Time	Price	Shares
10:20 AM	30.10	200
10:00 AM	30.10	100
10:20 AM	30.15	1000
10:00 AM	30.15	500
10:10 AM	30.15	100
10:00 AM	30.20	500

Order Book – Single Venue

Order Book

Sell Orders (Asks)

Time	Shares	Price	
10:00 AM	500	30.20	
10:20 AM	1000	30.15	
10:10 AM	100	30.15	
10:00 AM	500	30.15	
10:05 AM	200	30.10	
10:00 AM	100	30.10	Best Ask Price

Spread

Buy Orders (Bids)

Time	Shares	Price	
10:00 AM	100	30.00	Best Bid Price
10:05 AM	500	30.00	
10:15 AM	200	30.00	
10:00 AM	500	29.90	
10:20 AM	100	29.90	
10:10 AM	500	29.80	
10:15 AM	1000	29.80	

Sell Order Book: Asks
Collection of All Sell Orders
Price-Time Priority

Buy Order Book: Bids
Collection of all Buy Orders
Price-Time Priority

Order Book – Buy Order

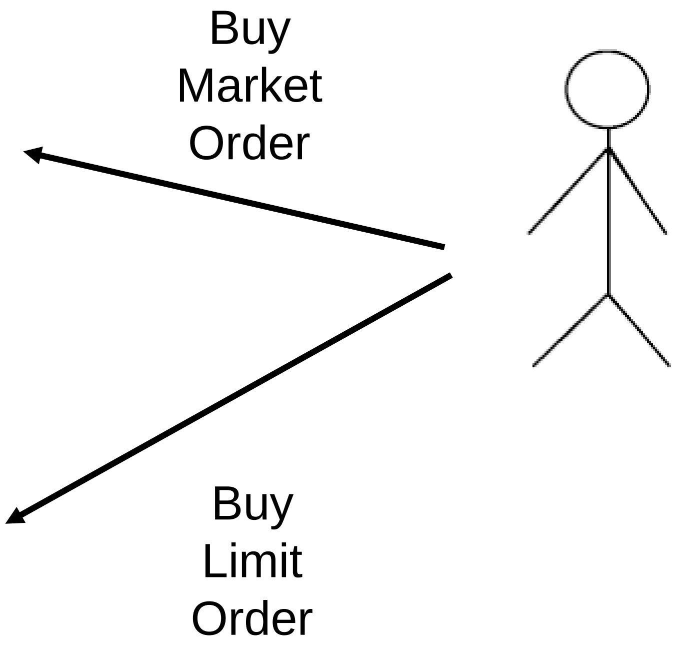
Order Book

Sell Orders (Asks)

Time	Shares	Price
10:00 AM	500	30.40
10:20 AM	1000	30.35
10:10 AM	100	30.20
10:00 AM	500	30.15
10:05 AM	200	30.10
10:00 AM	100	30.10

Buy Orders (Bids)

Time	Shares	Price
10:00 AM	100	30.00
10:05 AM	500	30.00
10:15 AM	200	30.00
10:30 AM	**100**	**30.00**
10:00 AM	500	29.90
10:20 AM	100	29.90
10:10 AM	500	29.80
10:15 AM	1000	29.80



Example: Buy Order

It is 10:30am. An investor wishes to buy 100 shares. She has two options:

i) Market Order = buy shares immediately at $30.10 by transacting at the best ask price.

ii) Buy Limit Order = enter a buy limit order into the order book at the current best bid price of $30.00. The order will not execute until all previously entered buy orders at $30.00 are executed. There is no guarantee that this order will execute.

Order Book – Sell Order

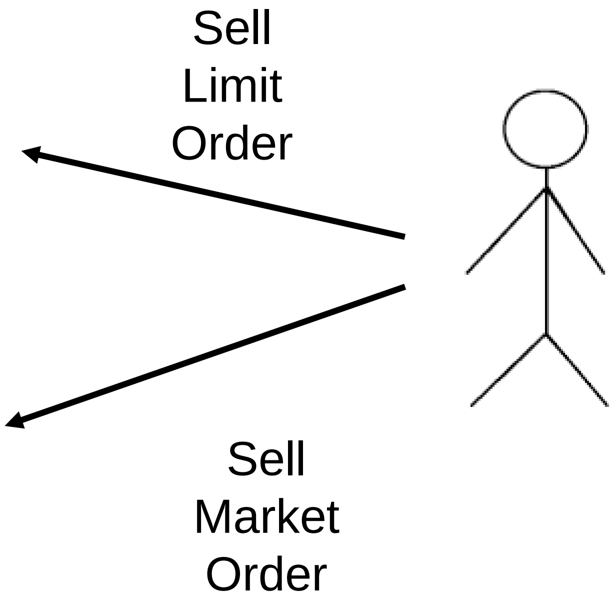
Order Book

Sell Orders (Asks)

Entry Time	Shares	Price
10:00 AM	500	30.40
10:20 AM	1000	30.35
10:10 AM	100	30.20
10:00 AM	500	30.15
10:30 AM	100	30.10
10:05 AM	200	30.10
10:00 AM	100	30.10

Buy Orders (Bids)

Entry Time	Shares	Price
10:00 AM	100	30.00
10:05 AM	500	30.00
10:15 AM	100	30.00
10:00 AM	500	29.90
10:20 AM	100	29.90
10:10 AM	500	29.80
10:15 AM	1000	29.80



Example: Sell Order

It is 10:30am. An investor wishes to sell 100 shares. She has two options:

i) Market Order = sell shares immediately at $30.00 by transacting at the best bid price.

ii) Sell Limit Order = enter a sell limit order into the order book at the current best ask price of $30.10. The order will not execute until all previously entered sell orders at $30.10 are executed. There is no guarantee that this order will execute.

Order Book - Multiple Venues

NBBO: National Best Bid - National Best Ask (Offer)
$30.02 - $30.06
$30.02 x 200 - $30.06 x 100

Venue A

Quote: Bid - Ask
$30.00 - $30.10
$30.00 x 800 - $30.10 x 300

Buy Orders (Bids) Price	Shares	Sell Orders (Asks) Price	Shares
30.00	100	30.10	100
30.00	500	30.10	200
30.00	200	30.15	500
29.90	500	30.15	100
29.90	100	30.15	1000
29.80	500	30.20	500
29.80	1000		

Venue B

Quote: Bid - Ask
$30.02 - $30.15
$30.02 x 200 - $30.15 x 600

Buy Orders (Bids) Price	Shares	Sell Orders (Asks) Price	Shares
30.02	**200**	30.15	500
30.00	100	30.15	100
30.00	500	30.20	500
29.90	1000	30.20	1000
		30.30	100
		30.30	200

Venue C

Quote: Bid - Ask
$29.90 - $30.06
$29.90 x 1600 - $30.06 x 100

Buy Orders (Bids) Price	Shares	Sell Orders (Asks) Price	Shares
29.90	500	**30.06**	**100**
29.90	100	30.10	300
29.90	1000	30.10	200
29.80	500	30.20	500
29.90	100	30.20	1000
		30.20	500

Trade Venue - Revenue Model

Venue Revenue Models (Rebates / Fees)

- **Maker-Taker Model**
  - The investor posting liquidity will receive a **“rebate”** from the trading venue. E.g., the investor who posts a limit order on the venue will receive a rebate if a trade occurs.
  - The investor taking liquidity is charged a **“fee”** by the trading venue. E.g., investors submitting a market order to the venue are charged a fee.
  - The difference between the Fee and Rebate is the profit for the Exchange/Venue.
- **Inverted Maker-Taker Model**
  - The investor posting liquidity is charged a fee.
  - The investor taking liquidity receives a rebate.
  - This is the opposite of the maker-taker revenue model.
- **Commission Based**:
  - Both parties are changed a **“commission”** for transacting in the venue.
  - This is a common revenue model with dark pools.

Venue Revenue Models (Rebates / Fees)

Revenue Model	Maker (Post Limit Order)	Taker (Trade with Market Order)
Maker-Taker	Receives Rebate	Pays Fee
Inverted Maker-Taker	Pays Fee	Received Rebate
Commission	Pays Fee	Pays Fee

Smart Order Routing

Market Order Book

Venue A

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	500	600
3	30.00	1000	1600
4	30.00	200	1800
5	30.00	100	1900
6	30.00	500	2400
7	30.00	200	2600

Venue B

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	500	600
3	30.00	200	800

Venue C

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	100	200
3	30.00	500	700
4	30.00	200	900
5	30.00	500	1400

Question

- The investor wishes to enter a Buy Limit order to by 100 shares at a price of $30.00.
- Which venue should the investor enter the order: Venue A, Venue B, or Venue C?

Market Order Book: Equal Volume at all Venues

Venue A

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	500	600
3	30.00	1000	1600
4	30.00	200	1800
5	30.00	100	1900
6	30.00	500	2400
7	30.00	200	2600
~~8~~	~~30.00~~	~~100~~	~~2700~~

Venue B

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	500	600
3	30.00	200	800
4	30.00	100	900

Venue C

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	100	200
3	30.00	500	700
4	30.00	200	900
5	30.00	500	1400
~~6~~	~~30.00~~	~~100~~	~~1500~~

- If there is equal volume traded at each venue, the investor should enter the buy limit order to Venue B because this venue has the fewest cumulative shares in the queue entered at $30.00.

Smart Order Routing

Market Order Book: Venue A trades 10x more volume than B and C

Venue A

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	500	600
3	30.00	1000	1600
4	30.00	200	1800
5	30.00	100	1900
6	30.00	500	2400
7	30.00	200	2600
8	30.00	100	2700

Venue B

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	500	600
3	30.00	200	800
~~4~~	~~30.00~~	~~100~~	~~900~~

Venue C

Queue	Price	Shares	Cumul. Shares
1	30.00	100	100
2	30.00	100	200
3	30.00	500	700
4	30.00	200	900
5	30.00	500	1400
~~6~~	~~30.00~~	~~100~~	~~1500~~

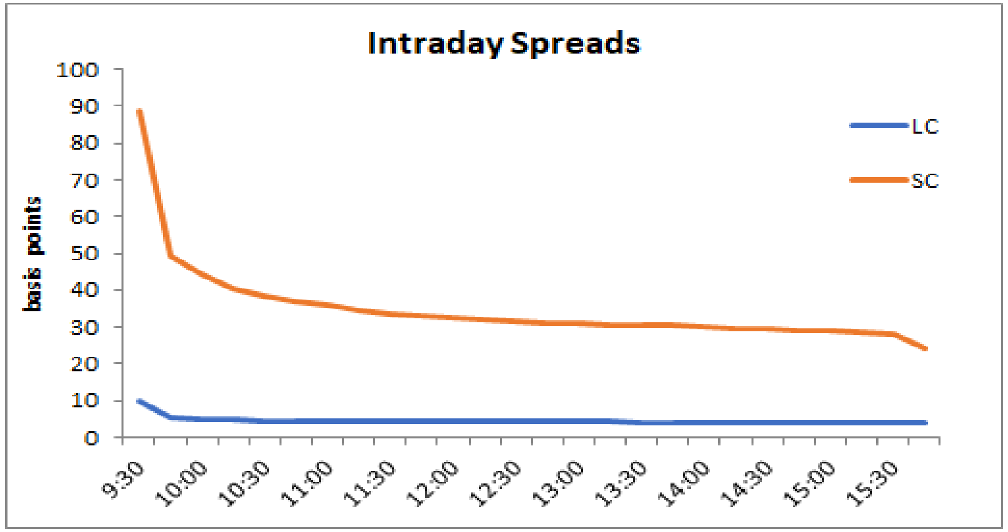
- If Venue A trades 10x the volume as Venue B and Venue C, the investor would be best served if they entered the limit order to venue A.
- Even though Venue A has the most cumulative shares that must execute before the investor will have their shares transacted, these shares are expected to transact quicker due to the much higher volume in venue A.
- Investors must consider the expected time until they are next in que, which is dependent upon the cumulative shares already entered into the order book and the trading volume at each volume.

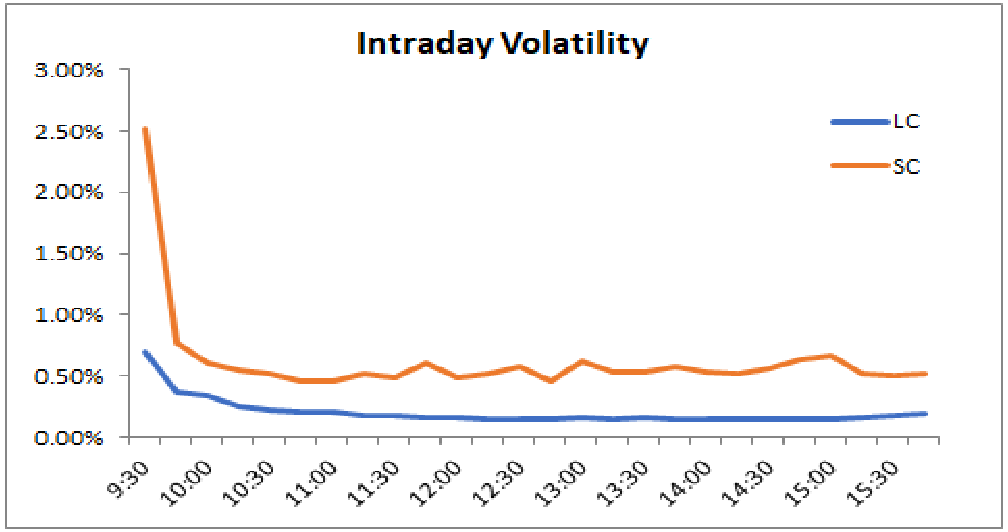
Market Microstructure Research

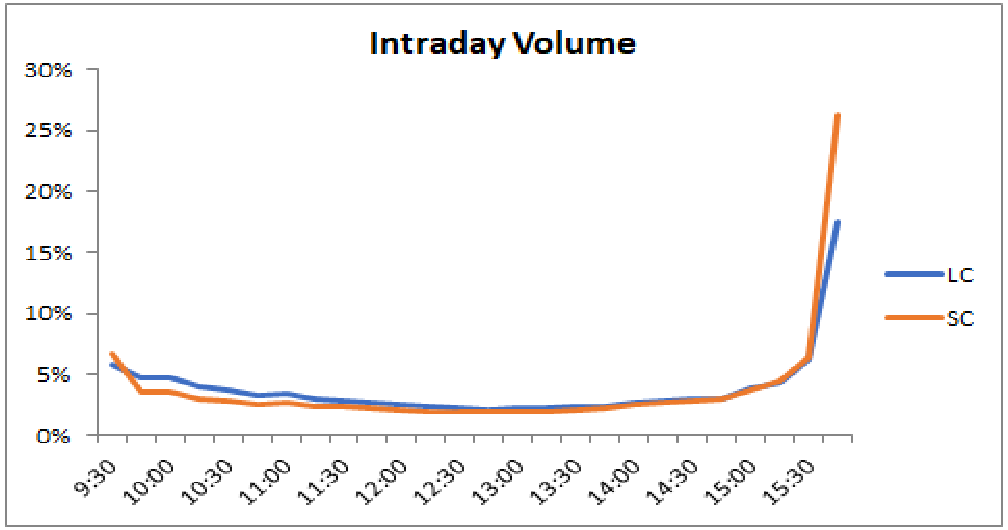
Market Microstructure

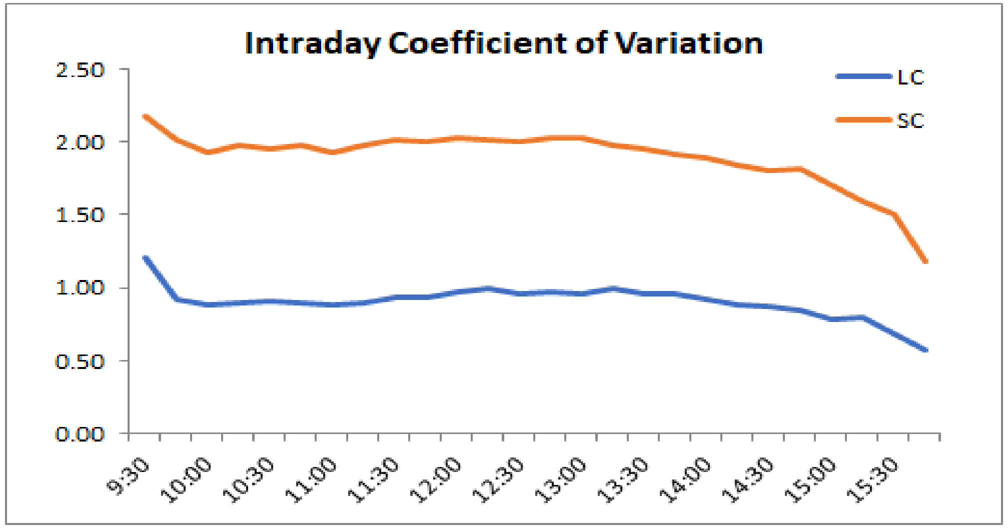
- Market microstructure is the study of financial markets and how they operate.
- Market microstructure research primarily focuses on the structure of exchanges and trading venues, the price discovery process, determinants of spreads and quotes, intraday trading behavior, and transaction costs.
- Market microstructure continues to be one of the fastest growing fields of financial research due tot the rapid development of algorithmic and electronic trading.
- It is also the underlying foundation behind the more profitable trading strategies, e.g., hedge funds, HFT, quant money managers, etc.

Intraday Trading Patterns



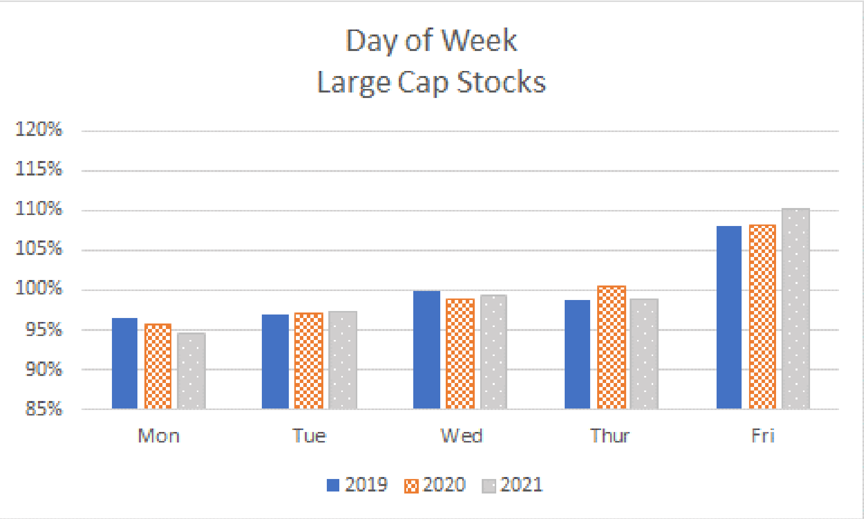


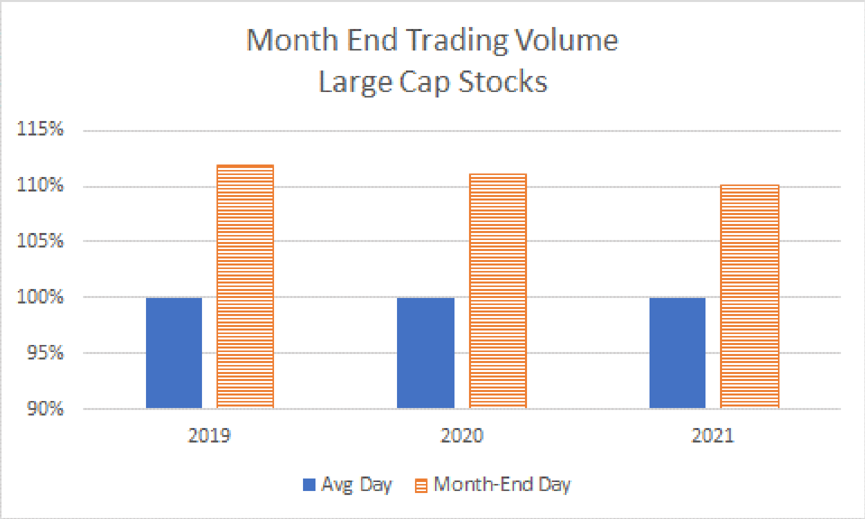


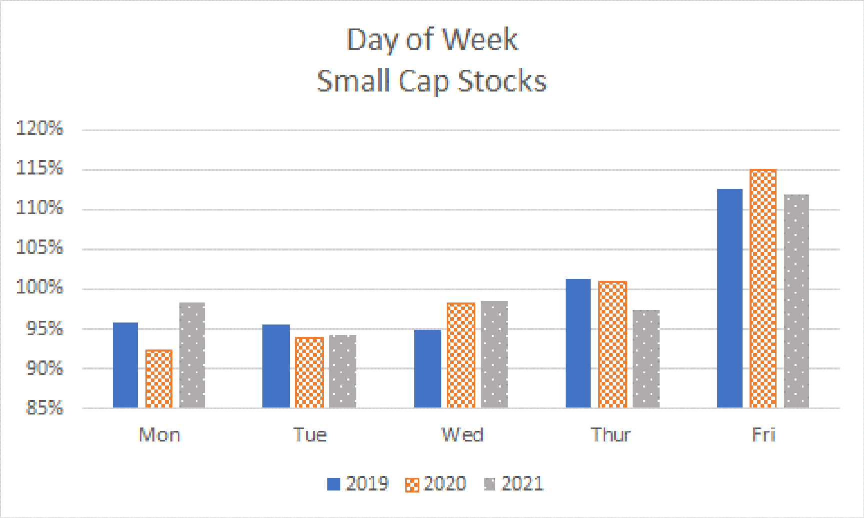


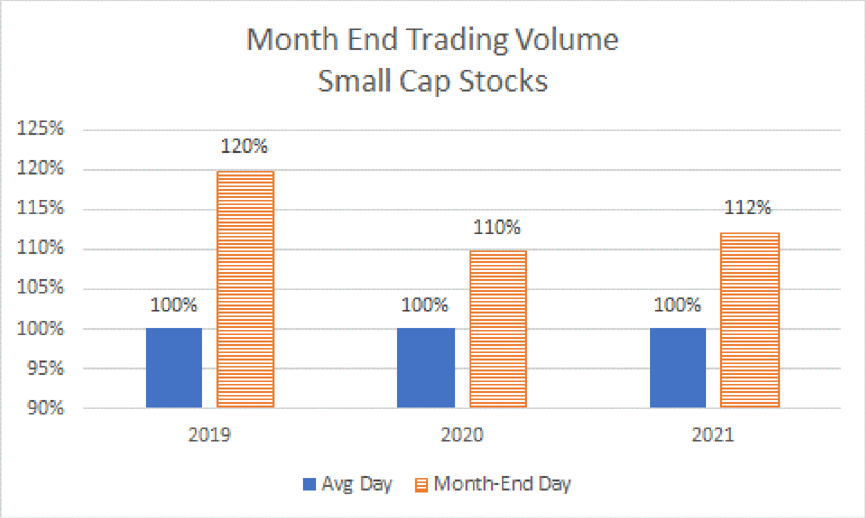
Source: Kissell Research Group (2022)

Day of Week Effect









Source: Kissell Research Group (2022)

Transaction Costs

What are Transaction Costs?

- Economic: dollars paid by buyers but not received by sellers and dollars paid by sellers but not received by buyers.
- Financial: dollars amount paid above the decision price (premium) for buy orders and dollars amount paid below the decision price (discount) for sell orders.
- Transaction costs are an unavoidable cost of business.
- Transaction costs consist of nine (9) cost components: i) commissions, ii) spreads, iii) taxes, iv) fees & rebates, v) delay cost, vi) price appreciation, vii) market impact, viii) timing risk, and ix) opportunity cost.

Transaction Cost Iceberg

Depiction of the Iceberg to illustrate Transaction Costs was introduced by Wayne Wagner, The Plexus Group (1990).

Transaction Cost Components: Visible Cost Components

Visible Cost Components:

- **Commissions** = paid to brokers to execute the order.
- **Fees & Rebates** = payment to the trade venue (depending on the structure, some investors may pay a fee and other investors may receive a rebate).
- **Bid-Ask Spread** = difference between the ask price and bid price. It represents the total cost of trading, e.g., buy on the ask and sell on the bid.
- **Taxes** = SEC transfer tax paid by the seller.

Transaction Cost Components: Hidden Cost Components

Hidden Cost Components:

- **Delay Cost** = the cost due to the price change in the stock between the time of the investment decision and the time the order is entered into the marker for execution.
- **Price Appreciation** = the cost due to buying stock in a rising market and/or selling stock in a falling market.
- **Market Impact** = the price movement in the stock due to the buying and/or selling pressure of the investor. Market impact consists of two components: temporary and permanent. Temporary market impact is the cost due to the liquidity needs of the investors. Permanent market impact is the cost due to the information content of the trade.
- **Timing Risk** = the cost due to market uncertainty, e.g., price volatility, volume variance, etc.
- **Opportunity Cost** = the missed profit opportunity for not being able to complete your entire order.

Implementation Shortfall

Implementation Shortfall (IS)

- Implementation Shortfall (IS) represents the total cost of executing the investment idea (Perold, 1988).
- Calculated as the difference between the paper return of a portfolio where all shares are assumed to have transacted at the manager's decision price and the actual return of the portfolio using actual transaction prices and shares executed.
- Described as the missed profiting opportunity of the investment idea as well as the friction associated with executing the trade. Many industry participants refer to implementation shortfall as slippage or simply portfolio cost.
- Expanded Implementation Shortfall (Wagner, 1993) provides a detailed explanation of where costs occur during implementation. These include:
  - Delay Cost, Execution Cost, Opportunity Cost, and Fixed Costs

Implementation Shortfall (IS)

Implementation Shortfall Components:

- **Delay Cost** = price movement in the stock from the time of the investment decision until the order is released to the market.
- **Execution Cost** = price movement in the stock over the time the order is being executed in the market.
  - Market Impact (MI), Price Appreciation (PA), Timing Risk (TR)
- **Opportunity Cost** = the missed profit opportunity of not being able to execute all shares in the order.
- **Fixed Cost** = all fixed fees charged during implementation of the trade.
  - Commission, Fees & Rebates, Spread, and Taxes

Implementation Shortfall (IS)

Formula:

$$IS_{\$} = \underbrace{S \cdot (P_0 - P_d)}_{Delay\ Cost} + \underbrace{X \cdot \left(P_{avg} - P_0\right)}_{Execution\ Cost} + \underbrace{R \cdot (P_n - P_0)}_{Opportunity\ Cost} + Fixed\ Cost$$

Variables:

S = Order Shares

X = Executed Shares

R = Unexecuted Shares

P_0 = Arrival Price - mid-point of bid-ask spread at time of order entry

P_d = Decision Price - mid-point of bid-ask spread at time of decision

P_n = End Price - mid-point of bid-ask spread at end time of (completion/cancel)

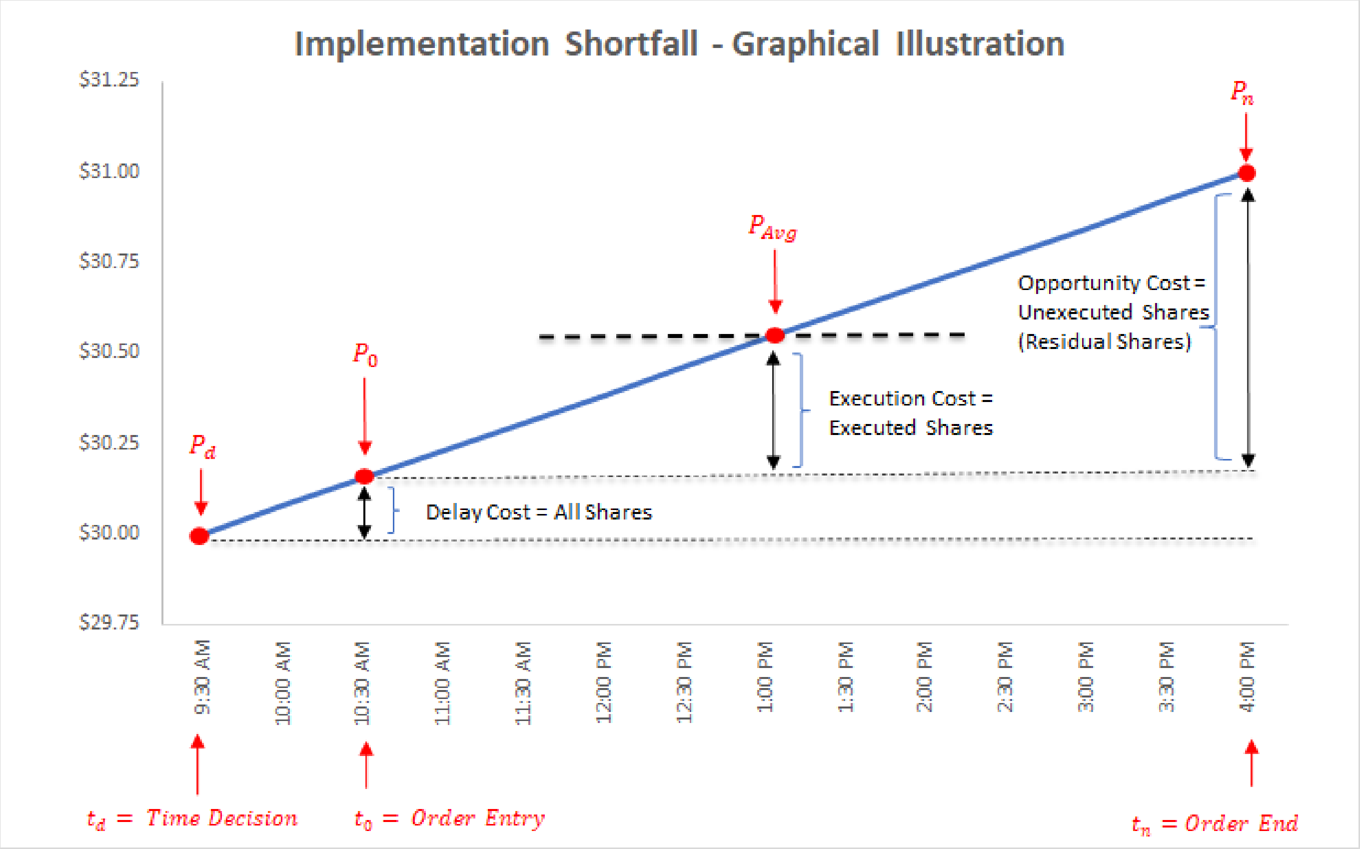
P_{Avg} = Average Execution Price of the Order

Fixed Cost = Commissions, Taxes, and Fees & Rebates

Spread Costs are embedded in the actual execution price of the stock

Fees & Rebates are often included in the broker commission

Implementation Shortfall (IS)



$$IS = \underbrace{S \cdot (P_0 - P_d)}_{Delay\ Cost} + \underbrace{X \cdot \left(P_{avg} - P_0\right)}_{Execution\ Cost} + \underbrace{R \cdot (P_n - P_0)}_{Opportunity\ Cost} + Fixed\ Cost$$

Implementation Shortfall (IS)

Example:

A manager decides to purchase 100,000 shares of RLK at $30.00. By the time the order is entered into the market the price has increased to $30.15. The manager buys 80,000 shares at an average price of $30.50. At the end of trading RLK is $31.00. The broker commission cost for the trade is $0.02/share.

Calculate the Implementation Shortfall of this trade and all cost components.

$$IS_{\$} = \underbrace{S \cdot (P_0 - P_d)}_{Delay\ Cost} + \underbrace{X \cdot \left(P_{avg} - P_0\right)}_{Execution\ Cost} + \underbrace{R \cdot (P_n - P_0)}_{Opportunity\ Cost} + Fixed\ Cost$$

$$IS_{\$/Share} = \frac{IS_{\$}}{Total\ Shares}$$

$$IS_{bp} = \frac{IS_{\$}}{Order\ Value} \cdot 10{,}000\ bp$$

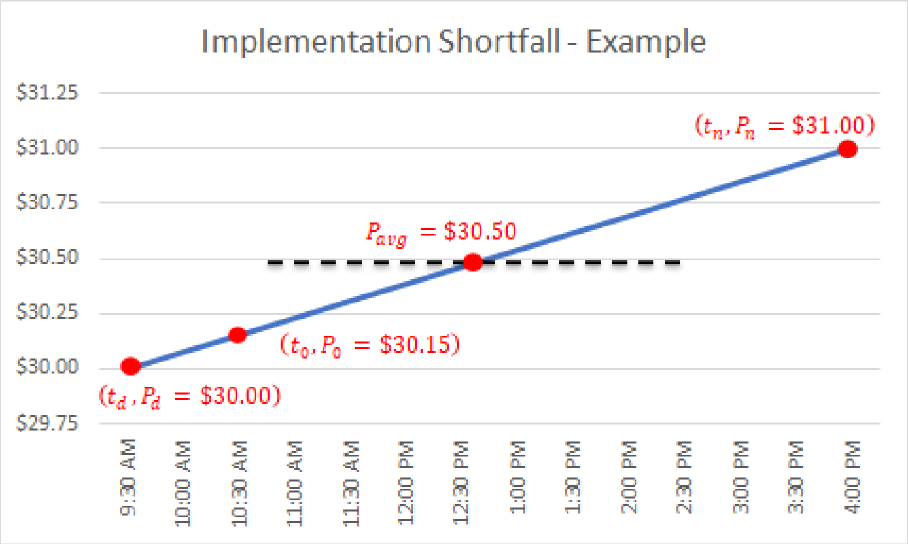
Implementation Shortfall (IS)

Example:

A manager decides to purchase 100,000 shares of RLK at $30.00. By the time the order is entered into the market the price has increased to $30.15. The manager buys 80,000 shares at an average price of $30.50. At the end of trading RLK is $31.00. The broker commission cost for the trade is $0.02/share.

Calculate the Implementation Shortfall of this trade and all cost components.

Implementation Shortfall - Example						
Pd=	$30.00		Order Shares =	100,000		
P0=	$30.15		Executed =	80,000		
Pn=	$31.00		Residual =	20,000		
Pavg=	$30.50					
comm =	$0.02		Order Value=	$3,000,000		
Component		**Shares**	**Chg**	**Dollars**	**$/Share**	**bp**
Delay	Pd-P0	100,000	$0.15	$15,000	$0.15	50.0
Execution	Pavg-P0	80,000	$0.35	$28,000	$0.28	93.3
Opportunity	Pn-P0	20,000	$0.85	$17,000	$0.17	56.7
Fixed	comm.	80,000	$0.02	$1,600	$0.02	5.3
Total				$61,600	$0.62	205.3



$$IS_\$ = \underbrace{100{,}000 \cdot (\$30.15 - \$30.00)}_{Delay\ =\ \$15{,}000} + \underbrace{80{,}000 \cdot (\$30.50 - \$30.15)}_{Execution\ =\ \$28{,}000} + \underbrace{20{,}000 \cdot (\$31.00 - \$30.15)}_{OC\ =\ \$17{,}000} + \underbrace{80{,}000 \cdot \$0.02}_{Fixed\ =\ \$1{,}600} = \$61{,}600$$

Implementation Shortfall – Cost Verification

Implementation Shortfall - Example				
Pd=	$30.00		Shares =	100,000
P0=	$30.15		Executed =	80,000
Pn=	$31.00		Residual =	20,000
Pavg=	$30.50			
comm =	$0.02		Order Value=	$3,000,000

$$Paper\ Return(\$) = 100{,}000 \cdot (\$31.00 - \$30.00) = \$100{,}000$$

$$Actual\ Return(\$) = 80{,}000 \cdot (\$31.00 - \$30.50) - 80{,}000 \cdot \$0.02 = \$40{,}000 - \$1{,}600 = \$38{,}400$$

$$IS(\$) = Paper\ Return\ - Actual\ Return = \$100{,}000\ - \$38{,}400 = \$61{,}600$$

$$IS(\$) = \$61{,}600$$

$$IS(\$) = \underbrace{S \cdot (P_0 - P_d)}_{Delay\ Cost} + \underbrace{X \cdot \left(P_{avg} - P_0\right)}_{Execution\ Cost} + \underbrace{R \cdot (P_n - P_0)}_{Opportunity\ Cost} + Fixed\ Cost$$

Transaction Cost Analysis (TCA)

Transaction Cost Analysis (TCA)

- Transaction Cost Analysis (TCA) or Post-Trade Analysis.
- This analysis is used to measure the Trading Cost of the order and to evaluate the performance of the Broker and/or Algorithm
- Some of these calculations will also measure the net difference between execution price and a future price (e.g., tracking error), and to help distinguish between temporary and permanent market impact. Cost.
- Benchmark analysis is always calculated based on the number of shares traded. This can be less than the order size if not all shares were calculated in the market.
- Calculations are provided in basis points, $/share, and total $.

Benchmark Analysis

- **Pre-Trade: -** Provides a measure of trading cost.
  - –Open Price – as a proxy for arrival price.
  - –Arrival Price – stock price at the time the order was entered to the market.
- **Intra-Day: -** Provides a measure of trading performance.
  - –VWAP – Volume Weighted Average Price over the Day
  - –Interval VWAP – Volume Weighted Average Price over the Trading Horizon
- **Post-Trade: –** Provides a measure of trading profitability
  - –Close Price –insight into end-of-day tracking error and is more commonly used by index funds that use the closing price in valuation of the fund.
  - –Next Day's Open – as a way to distinguish between temporary and permanent market impact.
  - –Next Day Close or Future Day Close – also to distinguish between temporary and permanent impact.

Benchmark Analysis

The benchmark cost calculation is:

$$Cost(\$) = Side \cdot \left(P_{avg} - P_B\right) \cdot \text{Executed Shares}$$

$$Cost(\$/Share) = Side \cdot \left(P_{avg} - P_B\right)$$

$$Cost(\$) = Side \cdot \frac{P_{avg} - P_B}{P_B} \cdot 10^4_{bp}$$

where,

P_{avg}= Average Execution Price

P_{B}= Price Benchmark

$Side$= 1 if Buy, -1 if Sell

Benchmark Analysis

Example:

A portfolio manager bought 100,000 shares of a 150,000 shares order at an average price of $P_{avg} = \$50.75$. The benchmark prices on the day are as follows: Open = $50.15, Arrival = $50.30, VWAP = $50.72, and Close = $50.90. Calculate the benchmark costs for Open, Arrival, VWAP, and Close in dollars, $/share, and basis points.

Benchmark Analysis

Example:

A portfolio manager bought 100,000 shares of a 150,000 shares order at an average price of $P_{avg} = \$50.75$. The benchmark prices on the day are as follows: Open = $50.15, Arrival = $50.30, VWAP = $50.72, and Close = $50.90. Calculate the benchmark costs for Open, Arrival, VWAP, and Close in dollars, $/share, and basis points.

Benchmark Analysis			
Open =	$50.15	Order Shares =	150,000
Arrival =	$50.30	Executed =	100,000
VWAP =	$50.72	Residual =	50,000
Close =	$50.90		
Pavg=	$50.75		

Open Cost:

Dollars ($): $+1 \cdot (\$50.75 - \$50.15) \cdot 100{,}000 = \$60{,}000$

$/share: $+1 \cdot (\$50.75 - \$50.15) = \$0.60$

Basis Points (bp): $+1 \cdot \frac{\$50.75 - \$50.15}{\$50.15} \cdot 10^4 = 119.64$

Arrival Cost:

Dollars ($): $+1 \cdot (\$50.75 - \$50.30) \cdot 100{,}000 = \$45{,}000$

$/share: $+1 \cdot (\$50.75 - \$50.30) = \$0.45$

Basis Points (bp): $+1 \cdot \frac{\$50.75 - \$50.30}{\$50.30} \cdot 10^4 = 89.46$

Close Cost:

Dollars ($): $+1 \cdot (\$50.75 - \$50.90) \cdot 100{,}000 = -\$15{,}000$

$/share: $+1 \cdot (\$50.90 - \$50.90) = -\$0.15$

Basis Points (bp): $+1 \cdot \frac{\$50.75 - \$50.90}{\$50.90} \cdot 10^4 = -24.47$

VWAP Cost:

Dollars ($): $+1 \cdot (\$50.75 - \$50.72) \cdot 100{,}000 = \$3{,}000$

$/share: $+1 \cdot (\$50.75 - \$50.72) = \$0.03$

Basis Points (bp): $+1 \cdot \frac{\$50.75 - \$50.72}{\$50.72} \cdot 10^4 = 5.91$

Performance Measures

Relative Performance Measure (RPM)

RPM: The Relative Performance Measure (RPM) is a percentile ranking of your trading activity. It provides the percentage of trading activity that the investor outperformed in the market.

- For a buy order, it represents the percentage of market activity that transacted at a higher price.
- For a sell order, it represents the percentage of market activity that transacted at a lower price.
- The RPM is modeled after the percentile ranking used in standardized academic tests and provides a descriptive statistic that is more consistent and robust than other measures.

$$\mathrm{RPM}(Buy) = \frac{1}{2} \cdot \left(\frac{Total\,Volume + Volume\ at\ Price > P_{Avg} - Volume\ at\ Price < P_{Avg}}{Total\,Volume} \right)$$

$$RPM(Sell) = \frac{1}{2} \cdot \left(\frac{Total\,Volume + Volume\ at\ Price < P_{Avg} - Volume\ at\ Price > P_{Avg}}{Total\,Volume} \right)$$

Relative Performance Measure - Example

Example:

The execution price for an order was $P_{avg} = \$25.00$. The total market volume was 100,000 shares. The volume greater than $25.00 was 20,000 shares. The volume less than $25.00 was 60,000 shares.

- What is the RPM if this was a Buy Order?
- What is the RPM if this was a Sell Order?

$$RPM(Buy) = \frac{1}{2} \cdot \left(\frac{100{,}000 + 20{,}000 - 60{,}000}{100{,}000} \right) = 0.30 = 30\%$$

$$RPM(Sell) = \frac{1}{2} \cdot \left(\frac{100{,}000 + 60{,}000 - 20{,}000}{100{,}000} \right) = 0.70 = 70\%$$

Broker Value-Add

Value-Add Analysis is used to determine if the realized transaction costs were appropriate given the actual market conditions during the trading horizon.

A Z-Score is used to adjust the value-add metric for the risk of the trade.

These value-add metrics are calculated using the Arrival Cost of the trade and the Expected Cost for the actual number of shares executed in the market under actual market conditions.

- Expected Cost is calculated as the expected market impact cost for the number of shares executed.
- Expected Market Impact cost is calculated based on actual market conditions.
- We can also make an adjustment for general market movement, e.g., Beta Adjusted Cost.

Important Note:

- For a High-Touch Trade and some Algorithms = it is not appropriate to adjust for market movement. E.g., an algorithm intended to protect investors from market movement.
- For Some Algorithms it may be appropriate to adjust for market movement, e.g., a VWAP algorithm or other user specified instructions.

Broker Value-Add

Depending on the needs of the investor, the Estimated Market Impact Cost may include an adjustment for general market movement, such as a Beta Adjusted Cost.

- A positive Value-Add indicates out-performance.
- A negative Value-Add metric indicates under-performance.

These formulas are as follows:

$$Value\ Add = Est.MI\ - Arrival\ Cost$$

$$Z\ Score = \frac{Est.MI\ - Arrival\ Cost}{TR} = \frac{Value\ Add}{TR}$$

Broker Value-Add

Example:

An investor executes 100,000 shares of a 150,000 share order. The arrival cost for the order was 60bp. The estimated market impact (MI) and timing risk (TR) for this scenario is below. What are the value-add calculations of this order?

Shares	MI	TR
150,000	70 bp	130 bp
100,000	50 bp	90 bp

Solution:

- Arrival Cost = 60 bp
- Est. MI(100,000) = 50 bp
- Est. TR(100,000) = 90 bp

- $Value\ Add = 50bp\ - 60bp = -10bp$
- $Z\ Score = \frac{50-60}{90} = \frac{-10}{90} = -0.1111$

Examples

Example: Implementation Shortfall

A portfolio manager decides to buy 1,000,000 shares of RLK at 10am when its price is $25.00 and sends the order to her Buy-Side trading desk. The Buy-Side trading desk analyzes the order and determines the best broker to execute the order is Broker ABC using their “Iron-Man” algorithm. At 10:15am the order is entered into the market and the price of RLK is $25.10. Broker ABC executes 800,000 shares of RLK from 10:15am through the close at 4:00pm at an average price of $25.60. At 4:00pm the close price of RLK is $26.00. Broker ABC charges 3 cents commission, e.g., $0.03/share commission.

a. Calculate total Implementation Shortfall cost
b. Calculate all Implementation Shortfall cost components
c. Confirm your Implementation Shortfall calculation is the difference between the paper return and actual return of the order.

Example: Post Trade Analysis

A portfolio manager executed 200,000 shares of a 225,000 share Sell order at an average price of $45.10. The arrival price was P0=$45.25 and the VWAP price over the trading horizon was VWAP=$45.05.

a) Calculate Arrival Cost in basis points (bp)

b) Calculate VWAP Cost in basis points (bp)

Example: Relative Performance Measure (RPM)

The execution price for an order was $P_{avg} = \$35.00$. Using the accompanying table,

a) Calculate the RPM if this was a Buy Order?

b) Calculate the RPM if this was a Sell Order?

Price	Volume
34.50	15,000
34.75	25,000
35.00	20,000
35.10	25,000
35.65	35,000
	120,000

$$\text{RPM}(Buy) = \frac{1}{2} \cdot \left(\frac{Total\ Volume + Volume\ at\ Price > P_{Avg} - Volume\ at\ Price < P_{Avg}}{Total\ Volume} \right)$$

$$RPM(Sell) = \frac{1}{2} \cdot \left(\frac{Total\ Volume + Volume\ at\ Price < P_{Avg} - Volume\ at\ Price > P_{Avg}}{Total\ Volume} \right)$$

Example: Broker Performance

A trader attempted to buy 100,000 shares of stock RLK but was only able to execute 80,000 shares. The arrival price (price when the order was entered into the market) was P0=$50.00 and the average execution was Pavg=$50.18.

The estimated market impact and timing risk for 100,000 shares of RLK was MI=40bp and TR=90bp respectively.

The estimated market impact and timing risk for 80,000 shares of RLK was MI=30bp and TR=65bp respectively.

a) What is the Value-Add of this order?

b) What is the Z-score of this order?