An Overview of Algorithmic Trading

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Abstract

Trade Implementation is an extremely important phase of the investment cycle, but unfortunately, it has often been overlooked. Historically, investors would simply send their order to a broker who would transact the shares in the market without much intervention from the investor. But with the advent of algorithmic trading and electronic markets, investors now need to be much more proactive in their trading decisions. Investors need to select appropriate execution strategies for their orders and these strategies need to be consistent with the investment objective and motivation of the trade. This also requires selection of broker, algorithm, and algorithmic parameters. This chapter provides investors with an overview of the algorithmic trading environment and an algorithmic decision-making process to assist investors make appropriate trading decisions and to ensure that these implementation decisions are in the best interest of the fund.

Keywords:

Algorithmic Trading, Transaction Costs, Market Impact, Algorithmic Decision-Making Process, Exchanges, Dark Pools.

Introduction

This chapter provides an overview of the essential information required for algorithmic trading. The topics covered provide students with the necessary information that will allow them to properly select and specify trading algorithms to execute orders based on different trading needs and investment objectives. The materials and concepts presented will provide students with an understanding of:

- The Investment Cycle
- Algorithmic and Electronic Trading
- Different Types of Trading Algorithms
- Algorithmic Strategies
- Transaction Cost Components

- Transact Costs Analysis (TCA)
- Trading Venues (Exchanges, ATS, and Dark Pools)
- Broker Dealer Trading Desk
- Algorithmic Decision-Making Process

Investment Cycle

To help understand trading strategies and algorithmic trading it is essential to start with a review of the investment cycle. The investment cycle consists of four distinct phases. These are: asset allocation, portfolio construction, implementation, and portfolio attribution and are as follows:

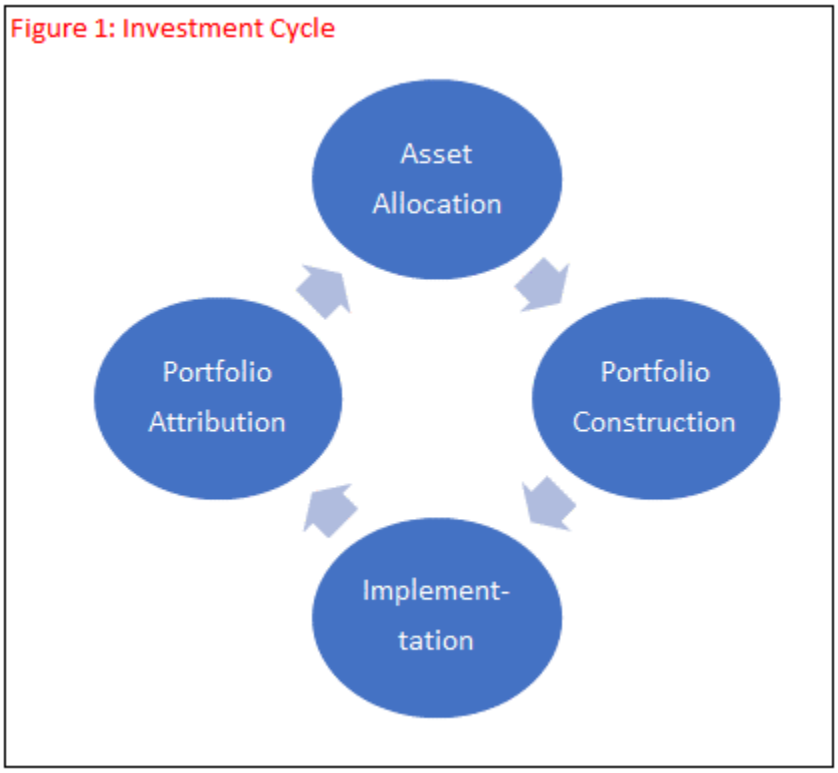
Asset Allocation. Asset allocation is the process of determining how much of the total investment dollar to allocate to stocks, bonds, cash, and other investment vehicles. This decision is made based on the investment objective of fund or via specified fund mandate.

Portfolio Construction. Portfolio construction is the process of selecting the actual individual investment instruments to hold in the portfolio. For example, for an equity portfolio this consist of determining which stocks should be bought and added into the portfolio or which stocks should be sold and removed from the portfolio. Portfolio construction will be based on the investment strategy of the fund and could be based on active or passive management, as well as fundamental, quantitative, or index investing. For a bond portfolio, portfolio construction consists of determining which corporate bonds to purchase and hold in the portfolio. This decision is often based on the bond rating (e.g., investment grade or high yield bond), as well as the current yield to maturity, years to maturity, probability of default, etc.

Implementation. The implementation phase of the investment cycle is the process of executing the portfolio managers' investment decisions. It consists of the actual buying and selling of stocks, bonds, etc. Implementation has historically consisted of selecting the appropriate broker for the execution, but with the advent of algorithmic trading, the implementation decisions are much more involved and require investors to be much more proactive in the trading decisions than ever before. Implementation now consists of selecting the broker, trading algorithm, and specifying the set of algorithmic trading rules and parameters to ensure the execution strategy will be consists with the underlying investment objective of the fund.

Portfolio Attribution. Portfolio attribution is the process of evaluating portfolio returns and risk, and comparing these values to expectations at the time of the investment decisions. Money managers are continuously reviewing their decisions to understand if the actual returns are due the investment strategy or due to some unanticipated event such as an economic boom or downturn, or company related news, or other items such as market noise, volatility, and/or luck. Portfolio attribution is a very important step in the investment cycle as it helps fund managers understand how well their strategies are working, and if they should continue with the strategy going forward. Portfolio attribution is a never-ending learning process.

Figure 1: Investment Cycle



Electronic and Algorithmic Trading

What is Electronic Trading?

Electronic trading is the process of entering and transacting order over a computer network. Historically, orders sent to brokers via phone calls and/or via 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 and the large majority of market trades occur via trading algorithms that are making execution decisions in real-time based on actual market conditions and stocks trends. And 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 will 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. The process showing how investors specify and determine these algorithmic trading decisions is provided below in the section titled Algorithmic Decision-Making Process.

Trading Algorithms can be classified into three categories:

- **Execution Algorithm.** An execution algorithm is an algorithm that will transact (trade) a given order following a set of specified rules and guidelines. In these situations, the money manager will determine the order independently of the algorithm and then enters the order characteristics consists of symbol, side, and shares into the algorithm. Investors will also specify other items such as start and end time for the order, price and/or volume limits if appropriate, as well as any preferred trading venues to venues where the investor does not want to transaction (possibly due to high potential of information leakage). The algorithm will then execution the order in the market following these instructions.

- **Profit Seeking Algorithm.** A profit seek algorithm is an algorithm that will make the investment decision (e.g., buy or sell decision) and will then execute this decision. The decision to buy or sell shares is based on market prices, investor strategy, and/or quantitative signals. In most of these situations, the profit seeking algorithm will utilize a quantitative model as the basis for its buy/sell decisions. For example, these algorithms may be running optimizations throughout the day, may be performing pairs trading analysis, or may be monitoring stocks for any type of market mispricing which may cause stocks to be under- or over-valued. Quantitative and statistical arbitrage strategies are also utilized by profit seeking algorithms to uncover additional value. It is important to note that these strategies are good for the market because all decisions are made based on publicly available prices. Additionally, these strategies do not have any specified holding period and could hold the positions (long and/or short) overnight or for days, weeks, months, or longer.

- **High Frequency Trading (HFT).** High frequency trading is a profit seeking strategy that seeks to earn a short-term trading profit in one of two ways. First, HFT algorithms function as electronic specialists and electronic market makers. They stand ready to buy shares at the bid and sell shares at the ask and earn the spread as a profit. They will also post liquidity to trading venues to receive a rebate from the venue in additional to earning the spread. Second, other types of HFT algorithms seek to uncover the trading intentions of other market participants by watching trading patterns and the submission of buy and sell order to the market. These algorithms will then use any information that they uncovered to gain an advantage in the market. For example, if a HFT algorithm has uncovered a large buy order in the market they will likely buying shares in conjunction with the investor. Then after prices have increased due to the price impact from the increased buying pressure they will sell the shares they bought at a higher price to earn a profit. It is important to note here that these HFT algorithms are using information that has been publicly disseminated to the market through trade reports and by viewing the order book at different venues. The information is not determined via any type of private information. If the HFT is incorrect with their assessment of an order they will incur a loss. But if the HFT is correct with their assessment they will earn a profit. An HFT strategy will almost always offset their position by the end of the day so that they do not incur any overnight risk.

Figure 2: Electronic and Algorithmic Trading

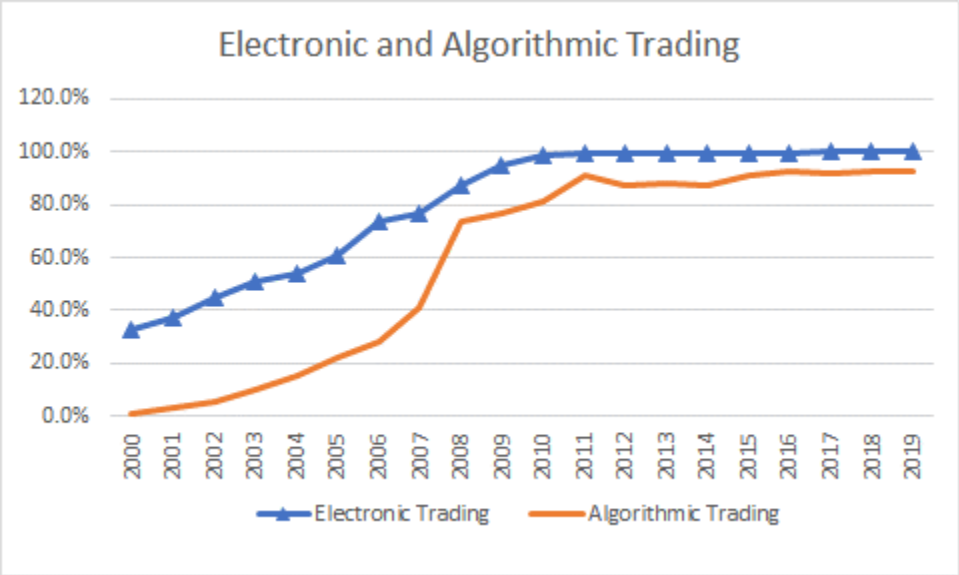
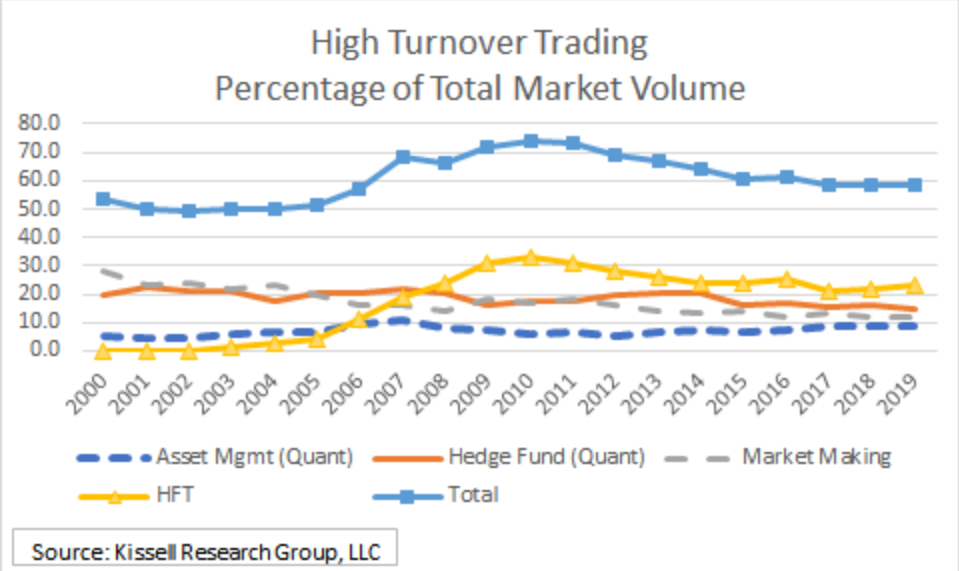


Figure 3: High Turnover Trading



Algorithm Trading Styles

There are many different types of trading algorithms used in the finance, and unfortunately, the naming conventions of these algorithms do not adequately describe what the algorithm is trying to accomplish or how the algorithm will transact in the market. For example, algorithms often have fun and entertaining names such as “Superman,” “Tarzan,” “Marvelous,” as well as “Dynamic,” and “Splendid.” But while these names are amusing, they do not provide any type of description of what the algorithm is really trying to accomplish or how it will trade in the market.

To help investors understand how these algorithms will trade in the markets, we often classify algorithms into three distinct groups of aggressive, working-order, passive. This classification helps

Portfolio Managers select the algorithms that will transact in a manner consistent with the investment objective of the fund.

- **Aggressive.** The algorithm will trade very aggressively in the market and will continuously seek to transact shares at a specified price or better. These algorithms are also referred to in industry as "liquidity seeking" and "liquidity sweeping" algorithms as the goal is to often capture as much available market shares as possible at the specified price or better. These algorithms trade using more market orders than limit orders, and tend to execute in displayed "lite" venues much more often than in dark pools.

- **Working Order.** the algorithm will trade in the market following rules specified by the investor. These "working order" algorithms seek to balance the trade-off between cost and risk, and ensure consistence between trading and the investment objective of the fund. These algorithms will trade using an appropriate mix of limit and market orders. These algorithms utilize displayed venues and dark pools in a manner to ensure the trading strategy is most consistent with the investment objective of the fund.

- **Passive.** the algorithm will trade in a passive manner and will seek to transact at prices and with share quantities that will not affect market prices or quotes. Passive algorithms will trade using more limit orders than market orders, and will attempt trade more seek to trade more shares in dark pools than in lite venues whenever possible to minimize information leakage and to ensure that transactions to not convey signals to the market about the trading intentions of the fund.

Types of Trading Algorithms

In the financial industry there are many types of trading algorithms. And different brokers offer different types and variations of each. The more common types of algorithms used in trading are described below.

- **VWAP.** 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, intraday volume following a U-shaped pattern with more volume at the open and close than during midday. But more recently, intraday volume seems to follow more of a J-shaped pattern where there is more volume at the open and close than midday, but much more volume at the close than at the open.
- **TWAP.** A TWAP algorithms, 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.
- **POV.** A POV algorithm is an algorithm that will trade based on a percentage of market volume. These algorithms are specified in terms of a percentage of volume. 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 transact 100 shares.
- **Arrival Price.** An arrival price algorithm is an algorithm that will trade aggressive (faster) when market prices are near the arrival price of the order, that is, the market price when the order

was entered into the market. As market prices move further away from the arrival price the algorithm will tend to trade at a more passible (slower) manner.

- **Font-Load.** A front-load algorithm is an algorithm that trades more aggressive at the beginning of the order and more passible 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.
- **Back-Load.** A back-load algorithm is an algorithm is an 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.
- **Optimal Strategy.** An optimal strategy is an execution strategy that is determined through an optimization process. The more common optimal strategies are i) minimize the total cost of the trade due to market impact and price appreciation, ii) balance the trade-off between market impact cost and timing risk, and iii) maximize the probability of outperforming a specified price.
- **MOC.** A MOC or market on close algorithm is an algorithm that will 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. Also, once an order is entered into the closing auction of an exchange they are guaranteed to be executed but the order cannot be cancelled once entered.
- **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.
- **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. The liquidity seeking algorithms are often used by investors who are trying to exploit a market mispricing. 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 as long as they can complete the order.
- **Dynamic.** A dynamic trading algorithm is an algorithm that adapts to changing market conditions such as prices and volumes based on investor prespecified trading rules. These rules allow the algorithms to take advantage of market conditions and prices when appropriate. Dynamic algorithmic trading logic is also often integrated into the algorithms mentioned above.
- **Portfolio Algorithms.** A portfolio algorithm is a trading 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, also commonly known as Portfolio IS, will make transaction decisions based on the overall cost and risk of the basket. These algorithms will manage the risk of the trade list and take advantage of favorable market conditions whenever possible from the perspective of the trade list. Portfolio algorithms make trading decisions based on the overall trade list and not at the individual stock level.

Figure 4 shows the usage of different trading algorithms over the twenty-year period from 2000-2019. Figure 5 illustrates how different algorithms would slice an order that consists of 10% of the stock's average daily volume.

Figure 4: Trading Algorithm Usage

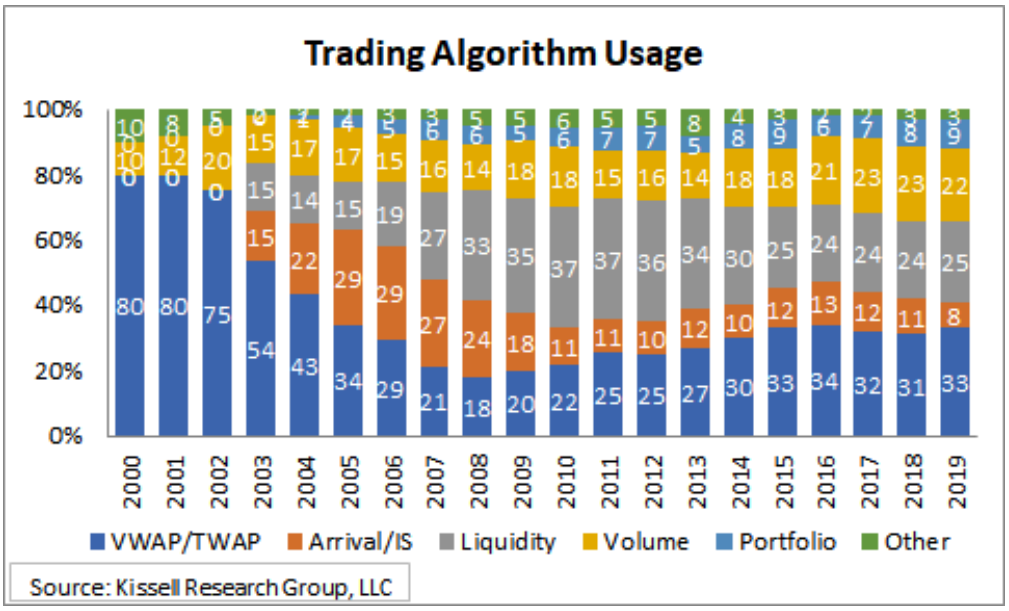
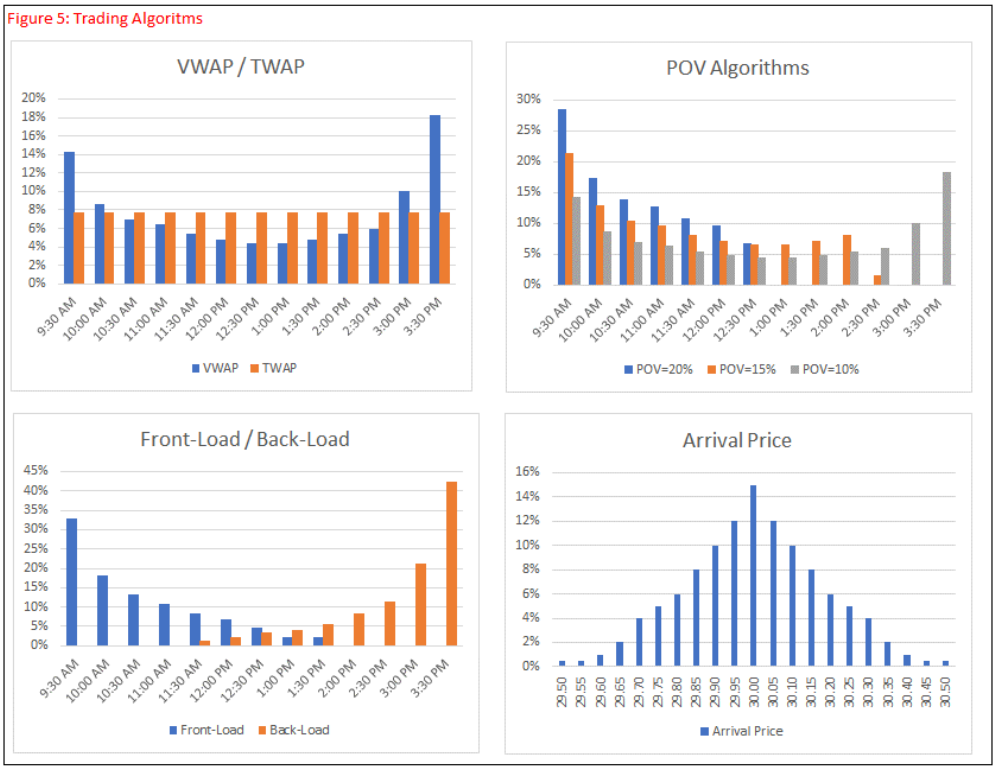


Figure 5: Trading Algorithm Strategies



Algorithmic Slicing Strategies

Trading algorithms are tasked with managing all transaction costs components over the trading horizon. In most cases, to minimize these costs the algorithms will slice the order and trade over time. There are three main ways that the algorithm will slice the order: time, volume, and price. These are described below.

- **Time Based** – a time based slicing strategy is a strategy that segments the order into trade buckets based on different time periods. The shares in each trade bucket can be based on historical volume profiles (such as a VWAP strategy) or ban be based on equal shares in each buck (such as a TWAP strategy). The number of shares to trade in these groups could also be calculated based on a quantitative model (such as the front-load, back-load, and optimal strategies). The algorithm is then tasked with executing each of these slices during the corresponding time interval.
- **Volume Based** – a volume based slicing strategy is an algorithmic strategy that participates with a specified quantity of volume. For example, a POV algorithm may specific to trade at a rate of POV=10%. In this case, the algorithm will need to participate with 10% of the market volume. If 1000 shares trades in the market, the algorithm will need to trade 100 shares. An advantage of a volume based POV algorithm provides the opportunity to participate with increased market volume and complete the order sooner. A disadvantage of a volume based POV algorithm is that if current volume is very low the order many not finish by the end of the day or by the specified end time. In times of illiquidity, investors will need to revise their POV rate to ensure completion of the order.
- **Price Based** – a price based slicing strategy is an algorithmic strategy that will transact different share quantities at different prices. A price based strategy is used by arrival price algorithms where more shares are transacted when market price is at or near the arrival price than when prices are further away from the arrival price. Some profit seeks and HFT algorithms will also utilize price based strategies to buy shares only if the price falls below a specified price or to sell shares if the price rises above a specific price.

Some of the more advanced trading algorithms will make use of a combination of the slicing strategies above. This allows investors to customize algorithms for their specific trading and investment needs. For example, we can utilize a combination of a volume-based and price-based slicing strategy so that the algorithm will be able to take advantage of increased volume and also trade at a faster rate when the prices are favorable but trade less urgently when prices are unfavorable.

Transaction Costs

In economics, transaction costs refer to the fees paid by buyers but not received by sellers and the fees paid by sellers but not received by buyers. In finance, transaction costs refer to the price premium paid above the decision price for buy orders and the discount below the decision price for sell orders.

When investors trade in the market, they encounter transaction costs that could dramatically affect portfolio performance and lead to much lower returns if not properly managers. Trading, unfortunately, is not a frictionless process and is often associated with numerous costs that are both visible (and easy

to calculate) and hidden (which can only be observed after trading takes place). In total, there are nine transaction cost components that arise during trading. These are:

Commissions. These are the fees paid to brokers for their service in transacting the order. Commissions are a visible trading cost component.

Fees & Rebates. These are the dollars paid to the trading venues (e.g., exchanges, ATS, and dark pools). In some situations, the investor will receive a rebate for the transaction and in other situations investors will pay a fee. Venue fees and rebates are a visible trading cost component.

Spread Cost. The difference between the highest bid price and the lowest ask price across all exchanges. In order words, the spread cost is computed from the NBBO (National Best Bid and Offer) prices and is a visible transaction cost component.

Taxes. Consists of SEC tax (on security sales), and income and capital gains taxes. Taxes are a visible transaction cost component.

Delay Cost. The cost due to the movement in the stock price from the time of the investment decision to the time that the order is entered into market for execution. For example, if a portfolio manager decides to purchase the stock when it is $30.00/share but by the time the order is entered into the market for execution the price is $30.25/share the manager incurred a cost of $0.25/share. Delay cost is a hidden transaction cost component.

Price Appreciation. The price appreciation cost is also referred to as the alpha cost. This is the natural price movement in the stock over the trading period. For example, if the stock price is increasing over the day due price appreciation, the manager will incur a higher transaction price which will make buy orders more expensive and sell orders more profitable since the executions will be made at higher prices. If the stock price is decreasing over the day due to price depreciation, the manager will incur a lower transaction price will make buy orders more favorable and sell orders more costly since the executions will be made at lower prices. Price appreciation is a hidden transaction cost component.

Market Impact. Market impact cost, also known as price impact, is defined as the price movement in the stock caused by the investor's trade or order. For example, a buy order causes increased demand in the stock which pushes the stock price up, and a sell order causes increased supply in the stock which pushes the stock price down. This follows the law of supply and demand from economics.

Market impact cost consists of two components: a temporary component and a permanent component. Temporary market impact cost is caused by the liquidity needs of the investor. Here, a buyer of stock may need to offer the market a premium to attract additional sellers into the market to complete the transactions. A seller of stock may need to discount their sale price (ask price) to entice buyers to purchase the shares. This temporary price change due to liquidity needs will be followed by trend reversion after the order is completed where the stock price will return to its fair value equilibrium price.

Permanent market impact cost is caused by the information content of the trade. At times when trading is perceived as information driven, meaning that we believe that there is some information that is leading the portfolio manager to buy or sell the stock that has not yet been fully disseminated and reflected in to the stock price, the market will reevaluate and adjust the valuation of the stock price

which will result in a new fair value. This results in a higher stock price after completion of a buy order and a lower stock price after completion of a sell order.

Market impact cost is one of the more expensive transaction cost components to investors and is caused solely by the order. Portfolio managers try to actively manage and control this cost throughout trading from the first to last trade.

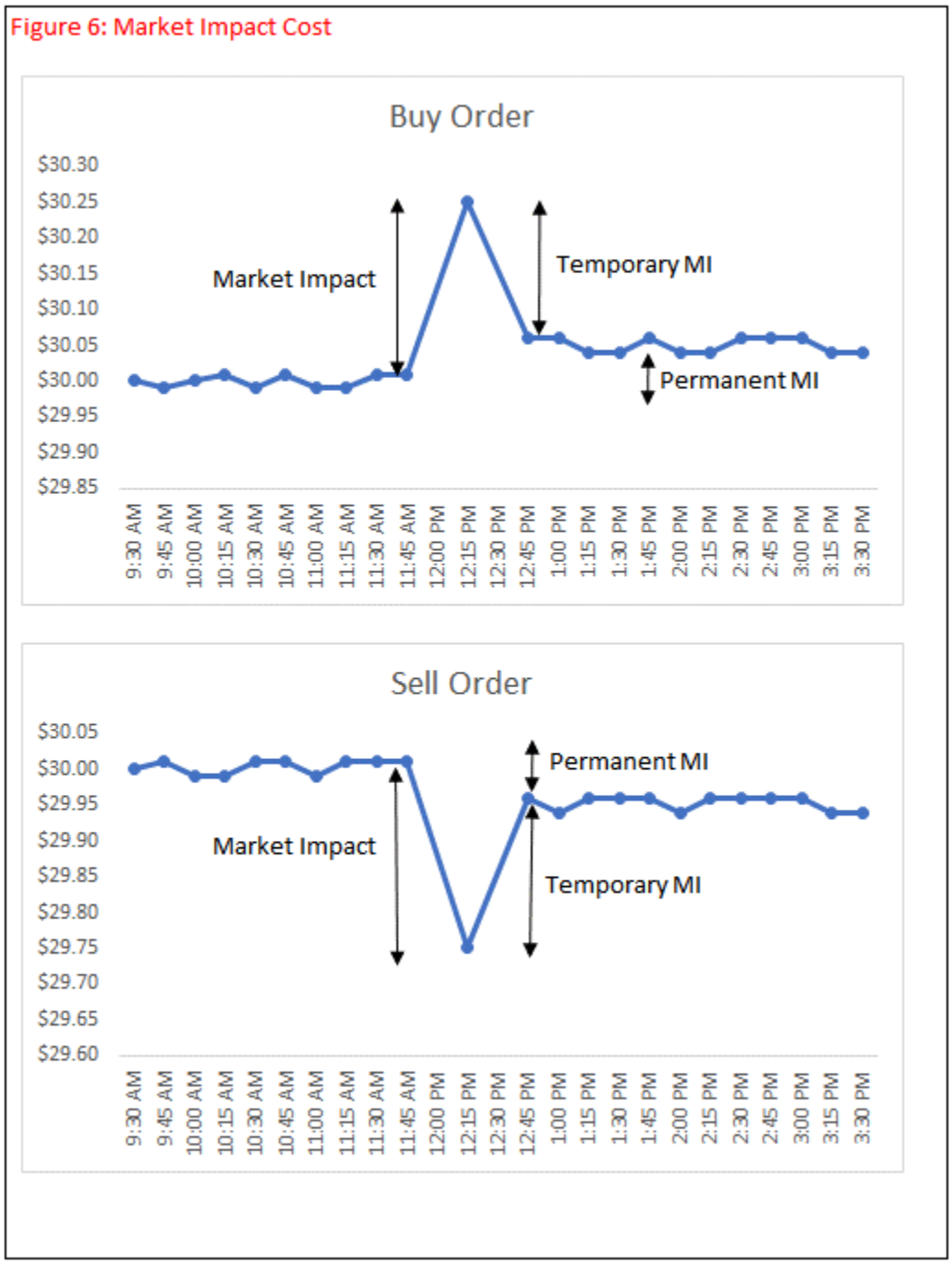
Market impact, unlike other transaction cost components, cannot be completely measured because we are only able to observe stock price movement without the order or stock price movement with the order, but not both. Because of this phenomenon, market impact cost has often been referred to as the Heisenberg Uncertainty Principle of Trading. Market impact cost is a hidden transaction cost component.

Timing Risk. Timing risk refers to the price uncertainty over the trading period where prices may increase or decrease due to factors that are not related to the order. Prices may increase or decrease during the trading horizon which makes transaction prices more or less expensive for the investor. Timing Risk is caused by price volatility, volume uncertainty, the buying and selling pressure from other market participants, and market noise. Timing risk is an unavoidable transaction cost component. It is a hidden transaction cost component.

Opportunity Cost. Opportunity cost is the cost associated with a missed profiting opportunity by not being able to execute the entire order in the market. For example, a portfolio manager decides to purchase 1,000,000 shares of stock RLK at the opening price of $30.00 and begins to trade at the market open. By the end of the day the price of RLK increases to $30.50, but the manager is only able to purchase 800,000 shares. Thus 200,000 shares of the order were not executed. If the portfolio manager were to execute these 200,000 shares at the market open the fund would have earned an additional $100,000 over the day, e.g., 200,000 * ($30.50 - $30.00) = $100,000. Opportunity cost is an unavoidable transaction cost component.

One of the primary goals of trading algorithms is to manage and control these transaction costs during implementation of the trade.

Figure 6: Market Impact Cost



Types of Implementation and Execution

After money managers decide what stocks they want to buy and sell and the corresponding number of shares, they need to decide how they will transact those shares in the market. Investors currently have two ways to execute the shares. These are known as agency execution and capital commitment (principal bid) transaction.

Agency Execution. An agency execution is a transaction where the investor pays the broker a commission to facilitate the trade. The broker or really the broker's algorithm then transacts shares in the market using best efforts until the order is completed. In this situation, the investor receives the exact transaction prices achieved by the algorithm. For example, if the investor has a buy order and the market prices increase then the investor will pay a higher price. If the market prices decline for a buy order then the investor will pay a lower price. If the investor has a sell order and the market prices decline the investor will have to sell the shares at a lower price, but if the market prices increase then the investor will be able to sell the shares at a higher price. In an agency execution, the investor does not know the price in advance and incurs all market risk. The investor pays the broker a commission to facilitate the trade.

For example, an investor has a buy order for RLK with a current stock price is $30.00 and the broker agency commission is $0.01. The algorithm completes the order at an average price of $30.10. In this case the investor will incur a total price including commission of $30.11 ($30.10 plus $0.01 commission) and the broker will earn their commission of $0.01.

Capital Commitment (Principal Bid) Transaction. A capital commitment trade, also known as a principal bid, risk bid, bid premium., or simply bid, is a transaction where the investor pays the broker a fee to transact the entire order at a specified price. In this case, the investor transacts a known price and transfers all risk to the broker. But the fee (e.g., bid) for this service is much higher than in an agency execution. The broker is then tasked with offsetting the order they just received from the investor in the market. If the broker can transact the order at a cost less than the bid amount received from the investor they will earn a profit. But if the broker incurs a cost higher than the bid received form the investor they will incur a loss.

In a capital commitment trade, the investor is provided with the exact transaction price by the broker and the bid. All risk is then transferred to the broker. The broker charges a higher price for a capital commitment than for an agency execution because they incur all risk of the trade. If the broker can transact in the market at a better price than they charged the investor they will incur a profit, but if they transact at a worse price they will incur a loss.

For example, an investor has a buy order for RLK with a current stock price is $30.00 and the broker bid premium is $0.15. In this case the investor will receive an all-in price (including the bid premium) of $30.15 (current price of $30.00 plus $0.15 bid premium). The broker will then purchase the shares in the market. If the broker purchases shares at a price of $30.15 or lower they will earn a profit. If the broker purchases shares at a price higher than $30.15 they will incur a loss. If the broker purchases shares at a price of exactly $30.15 they will break even. The principal bid premium here will be higher than the agency commission because it is to provide the broker with payment for accepting the risk of the trade.

Trading Venues

Historically, stocks were primarily traded on the exchange where they were listed. For example, a blue-chip stock listed on the NYSE exchange traded primarily on the floor of the NYSE and a technology company listed on the NASDAQ OTC exchange would trade primarily via NASDAQ market makers. The blue-chip NYSE listed company would not trade on the OTC exchange and the technology NASDAQ OTC listed company would not trade on the floor of NYSE.

But now, in a new electronic trading area, all stocks now trade in multiple venues consisting of exchanges, alternative trading systems, and dark pools. These are described as follows:

Exchange. An exchange is a venue where companies list their securities to be offered to the market. An exchange will ensure that the listed company has up-to-date financials and is properly adhering to the exchange's listing requirements which may include a minimum price and minimum daily volumes amongst other items. The exchange will help facilitate trading of the company and provide liquidity in the stocks via electronic market makers that are designated by the exchange. These electronic market maker firms are required to maintain fair and orderly pricings throughout the day, provide competitive bid and offer prices where they stand ready to buy shares and sell shares at their specified prices, and provide on-going market liquidity. A designated market maker firm may be provided with special rebates for their role that might be enticing than what is offered to other investors who are not required to help maintain fair and orderly markets and providing ongoing liquidity.

An exchange will maintain an order book for all stocks it trades. The order book includes all buy orders prices and shares, and all sell orders prices and shares. In the case where there may be multiple orders at the same price, the priority for execution will be defined by the exchange. The most common execution priority is given by best price and time (e.g., price-time priority). Some exchanges provide execution priority based on best price and largest share quantity (e.g., price-size priority). If there are multiple orders entered at the same price and share quantity, then the order that has been posted for the time will be executed first (e.g., price-size-time priority).

The exchange is responsible for publicly disseminating its best bid price and the best ask price and corresponding share quantities. The exchange is also required to report all trades executed. Exchanges may also provide order book information to investors which consist of all entered buy orders and sells orders including share quantity). Although investors may be required to pay a fee or an additional fee for access to this service.

Investor will use this information to determine how long it would likely take to execute an order placed at a specified price based on where they are in limit order book and how many orders are ahead of them in the queue.

- An exchange is a displayed market because it disseminates the best bid and best ask prices to the market.

Alternative Trading System (ATS). An alternative trading system (ATS) operates similar to an exchange but does not provide any listing services for companies or provide financial information on the company to investors. An ATS will trade stocks listed on exchanges, and will also disseminate pricing information including its best bid and best ask, as well as order book information. An alternative trading system will most commonly execute orders based on price-time priority.

Investor who seek to transact on an ATS will have access to the prices and order book information. But there may be an additional fee to gain access to the venues full order book. An important note about ATSs is that they have different reporting requirements. This information will allow investor to understand where they are in queue and they can then estimate how long it will likely take to execute their order.

- An alternative trading system is a displayed market because it disseminates the best bid and best ask prices to the market.

Dark Pool. A dark pool is a trading venue that does not provide any pricing information to investors. Investors utilizing a dark pool will enter an order and they will receive an execution if there is an offsetting order at the specified price or better. If the dark pool does not have a matching order or does not have an offsetting order at the desired price or better an execution will not occur. Additionally, a dark pool does not report its executed trades directly to public. Instead, trades that occur in a dark pool are publicly disseminated via FINRA's TRF (trade reporting facility) but the only information that is provided is that it was a dark pool trade with giving the exact dark pool where the trade occurred.

An advantage of using a dark pool is that it allows investors to enter large orders for execution without conveying their trading intentions and order size to the public. The order will only execute if there is an offsetting order at the specified price or better. Because neither order information or trade executions for the venue are disseminated publicly, it is often said that dark pools eliminate information leakage. However, investors are always concerned about the possibility of other investors learning information about their trading intentions, especially if they enter a large order, and as a result, will often enter smaller orders into dark pool.

- In most dark pools, orders are matched using the midpoint of the NBBO. Dark pools received their name because they do not provide investors with any pricing information and they do not add to the price discovery process.

Venue Pricing Models

In the current trading environment, each venue maintains a different pricing model. There are three primary venue pricing models. This is how venues earn their revenue. These are:

- **Commission-Fee Model.** In a commission-fee model, both the seller and the buyer pay the venue a commission to complete the trade. A commission based pricing model is most common with dark pools. For example, if the commission rate is 10 mills (e.g., $0.0010 per share which is 0.10 cents per share) and a trade occurs both the buyer and the seller pay the venue 10 mills each. Therefore, the venue earns 20 mills on the trade.

- **Maker-Taker Model.** A maker-taker model is a venue pricing model based on fees and rebates. In this structure, the market participant who posts an order to the exchange (and is disseminated publicly) will receive a rebate from the exchange if a match occurs and the market participant who takes the liquidity will pay a fee. Here, the party who posts an order (e.g., posts liquidity, provides liquidity) is making a market and is rewarded with a rebate for bringing liquidity to the venue when a trade occurs. The party who takes the liquidity is required to pay a fee. For example, in a maker-take pricing structure, the party posting liquidity may receive a

rebate of 10 mills and the party taking liquidity may pay a fee of 30 mills for the transaction. In this case, the venue earns a profit of 20 mills per share. A maker-taker venue pricing model is the most common pricing model used with displayed exchanges and venues.

- **Inverted Maker-Taker Model.** An inverted maker-taker model ("inverted") behaves in the opposite manner as the maker-taker model. In this case, the party posting liquidity will pay a fee of a match occurs and the party taking liquidity will receive a rebate. For example, an inverted maker-taker model may be one where the liquidity provider pays a fee 30 mills and the liquidity taker receives a rebate of 10 mills. In this case, the venue also earns a profit of 20 mills per share. An inverted maker-taker model is used for displayed exchanges and venues but is much less common than the traditional maker-taker model.

One question that commonly arises with regards to the maker-taker and inverted maker-taker model is why would an investor who is posting liquidity (e.g., entering a limit order) decide to pay a fee on an "inverted" venue when they could receive a rebate on the traditional venue? The answer is simple and comes down to how quick does the investor need to complete the order at their specified price.

For example, suppose an investor wishes to execute an order via a limit order placed at the best market bid but there are many orders at the same price in the queue ahead of the investor. This investor needs to wait until all the order in queue ahead of their order have executed before their order will transact (which may or may not occur). If this investor determines that the time that they will have to wait to have their order executed is too long they have three options that will result in quicker execution. First, they could execute via a market order which results in them paying a fee and a much higher price since they are crossing the entire bid-ask spread. This results in a much higher price and a fee. Second, they could increment the bid price by say a penny. In this case, their order would be the next one in the queue to be transacted because they would have the highest bid price and would be first in line since they increased the bid. In this case, the investor would receive their rebate but would pay a price that is $0.01 higher. Third, the investor could enter the order on an inverted exchange. In this case, the investor's order would effectively become the next order in the market queue to be executed because a seller would rather receive a rebate for taking liquidity than pay a fee for taking liquidity. In this case, the investor is able to buy shares at their specified price but they pay a fee to the venue rather than collect the rebate. An inverted maker-taker model behaves in the same manner as a fast-pass ticker at amusement parks that allows the customer to cut to the front of the line when the line is too long and the person does not want to wait. The customer receives the fast-pass but paid a premium to receive this luxury. So, the inverted model is the same as a go to the front of the line card for the investor – it comes with an increased cost but this increment cost is still less than the cost corresponding with having to increase the bid price.

Types of Orders

There are two main types of orders used in algorithmic trading: market order and limit order. These are:

- **Market Order.** A market order is an order that will trade at the best available market price. Here, a buyer would buy shares at the best (lowest) ask price in the market and a seller would sell shares at the best (highest) bid price in the market. There are rules in place that require

exchanges and venues to route an order to a different venue if that venue has a better price. Investors who trade via a market order are denoted as liquidity takers since they are taking volume away from the market.

- **Limit Order.** A limit order is an order where the investor specifies the highest price (bid) that they are willing to buy shares and the lowest price (ask) that they are willing to sell shares. Investors who trade via limit orders are denoted as liquidity providers since they provide liquidity to the market. Here, the investor would enter their buy or sell order into an exchange or ATS. The order would include the side (buy or sell), price, and share quantity.

Broker Dealer Trading Floor

A full-service broker dealer trading floor will commonly consist of three different trading desks: cash desk, program desk, and electronic desk. Each trading desk is utilized by an investor with a different trading need and serves a different purpose.

Cash Desk. A broker dealer cash trading desk is also known as a single stock trading desk or a block trading desk. Historically, the cash desk was used by investors to transact large block orders, but now, the cash desk is utilized by investors who are trading single orders that are subject to adverse price movement and/or momentum. In these situations, investors will rely on the broker's expertise in understanding stock specific trading patterns and whether or not the stock is likely to experience continued momentum patterns or trend reversal. A cash desk trader will have expertise in both the stock and the stocks sector, and will rely on real-time data and market conditions to help structure an appropriate trading strategy for the investor.

The cash desk trader will use the brokers trading algorithms to execute the single stock order. Then as market conditions change, they will likely execute faster or slower so that they can take advantage of the prevailing market conditions.

For example, the investor sends the cash desk a buy order to trade over the day using a POV algorithm. During trading the stock price increases. The broker determines that based on the stock's trading pattern, real time market conditions, and sector movement that the price is likely to exhibit mean reversion. In this case, the broker will likely reduce the algorithm POV rate and trade slower until prices revert to the stocks fair value, and then continue to trade at the initial rate. If the broker determined that they stock was more likely to exhibit continued momentum throughout the day, they would most likely increase the algorithm POV rate and trade faster to avoid the expected higher prices that towards the end of the day. Here the broker would want to complete the order before prices become too high due to the stock's price momentum.

Program Desk. A broker dealer program trading desk is also known as the portfolio trading desk. This desk is utilized by investor who are transacting baskets of stocks also known as trade lists, programs, and portfolios. The baskets may be one-sided and consist of buy orders only or sell orders only, or it may be two-sided and consist of buy orders and sell orders.

Investors who utilize a program desk may not necessarily be concerned about short-term price movement for an individual stock, but rather, they are mostly concerned about the overall cost and performance of the entire basket. In these situations, they rely on the expertise of the program trading desk to manage the overall risk of the trade list. The reason that investors are not necessarily concerned

about the performance for an individual stock is because the stocks in the basket are likely providing diversification and risk reduction.

For example, consider a basket that consists of buy and sell orders. As the market increases the buy orders become more expensive but the investor receives better prices for the sell orders which helps to offset the higher cost. As the market decreases the sell orders receive less favorable prices but the investor can transact the buys at a better price which helps to offset the less favorable sell prices. Here, the program desk is most concerned about managing the risk of the overall trade basket to protect the investor from market movement. As trading occurs, program traders will fine tune the trade list based on actual market conditions and seek to maintain a minimum risk position throughout trading.

An important consideration for a program trading is with respect to the type of portfolio risk management used during trading. Program algorithms will commonly employ an optimization algorithm that will balance the overall market impact cost across all stocks in the basket and the timing risk of the basket by incorporating price volatility and correlations across all stocks in the basket. The optimizer will be run throughout the day to ensure that trading strategies are consistent with the investment objective of the fund and will adjust to changing market conditions and price movement.

The trade basket can also be executed using "risk minimization" or "cash balancing" constraints which would be incorporated into the optimization process. A risk minimization constraint will ensure that trades occur so that the unexecuted shares will maintain a minimum level of risk given market conditions and prices. A risk minimization constraint is important for investors who are seeking to achieve a desired outcome such as a targeted return, risk level, or factor exposures. It is used for investment optimization and rebalances.

A cash balancing constraint will ensure that the actual executed shares have an equal dollar value across buys and sells. A cash balancing constraint is appropriate for investor who is using the proceeds from sales to finance the buys. It will ensure that the investor will not have to come up with any additional funds at the end of the day in case of unanticipated market movement or trading halts would could results in a higher dollar value bought than sold. In this case, the investor would need to send the broker additional capital to cover the buys.

It is important to note here that the risk minimization and cash balancing constraints behave in an opposite manner and it is essential that investors properly specify these constraints. For example, the risk minimization constraint will manage the "unexecuted shares" to maintain a minimal level of risk. The cash balancing constrain will manage "actual executions" to ensure that the buy value and sell value are the same.

Electronic Desk. The electronic trading desk, also known as the algorithmic trading desk, or simply the "Algo" desk, is the used by investors who wish to trade anonymously and want to have full control of their order. These investors will often utilize an electronic desk at times when they are not anticipating any type of short-term adverse price movement, and when they wish to specify exactly how their order is transacted in the market. Investors will use an electronic trading desk for small and large orders, and for both single stock and baskets.

An investor who is using an electronic desk may will use the same tools and algorithms that are used by the broker's cash and program desks. The only difference is that the investor will set and specify all

algorithmic parameters. An advantage of using an electronic trading desk to execute an order is that the investor (buy side trader) can to customize an algorithmic trading strategy exactly for their needs and to best achieve their investment objective without having to convey any information about their investment decision to the broker. A disadvantage of using an electronic trading desk is that the investor (buy side trader) will need to understand the intricacies of each algorithm to be able to properly specify trading instructions, which is not easy.

Investors may also select a broker electronic trading desk to utilize the brokers direct market access (DMA) services. DMA allows the investor to use the same algorithmic trading infrastructure as the broker, connect to the same trading venues and dark pools, and receive messages in the same manner as the broker. Here, investors are required to write their own trading algorithms which will often include the logic behind the buy and sell decisions such as via optimization, quant screens, and statistical arbitrage logic.

Using DMA allows investors to customize their own execution algorithms and often in ways that are not available via the broker algorithms. DMA also allows investors to incorporate their own investment instructions and quantitative models as part of the algorithms without conveying any information about their investment decision-making process to the market.

Figure 7: Broker Dealer Trading Desks

Figure 7: Broker Dealer Trading Desks

Broker-Deal Trading Desks			
Function	**Cash Desk**	**Program Desk**	**Electronic Desk**
Trading:	Single Stock / Blocks	Programs / Baskets Index / ETFs	Single Stocks / Baskets
Trading Concerns:	Price Movement Alpha	Risk Management Cash Balancing	Liquidity Control / Anonymity
Reason:	Company / Relationships Superior Products / Expertise Research Product Capital Commitment	Company / Relationships Superior Products / Expertise Research Product Risk Bids	Company / Relationships Superior Products / Expertise Algorithmic Products
Sales Team:	Equity Sales Corporate Access	PT Sales Quant Sales	Electronic Sales
Research Team:	Equity Research Economic Research Macro Research Sector Analysts	Quant Research Index Research	TCA Research
Research Products:	Price Targets Earnings Ratings	Quant Screens & Research Index & ETF Research Portfolio Analytics Risk Models / Optimizers Price Targets / Returns Pre- & Post-Trade TCA/Market Impact/Cost Curves Risk Bidding Summary	Pre- & Post-Trade Market Microstructure Portfolio Analytics Quant Research TCA/Market Impact Cost Curves Trade Schedule Optimizer

How does the reason behind the trade influence the selection of the trading algorithm?

To help us understand trading algorithms, and more importantly, which algorithms should be selected for with types of situations, it is important to consider the reason behind the trade. Below we discuss some of the more common reasons behind a trade and the most appropriate algorithms for each.

Short-Term Alpha View: A portfolio manager with a short-term alpha view is expecting the stock price to either increase or decrease in the short-term and often these price movements will occur very fast. In these situations, the portfolio manager will likely trade aggressively to capture as much of the short-term alpha as possible.

- Investors are best served in these situations by utilizing an aggressive trading algorithm.

Long-Term Alpha View: A portfolio manager with a long-term alpha view believes that the stock will achieve excess returns and long-term growth but the is currently appropriately priced in the market. In these situations, the portfolio manager will often choose to trade in a more passive manner in order to keep their trading intentions hidden and to minimize information leakage that may cause other market participations to draw the same conclusions about the long-term growth opportunity for the stock and thus increase the stock demand and stock prices in short-term.

- Investors are best served in these situations by utilizing a passive trading algorithm.

Stock Mispricing: At times stocks may be under- or over-valued in the market. While financial theory and the efficient markets hypothesis leads us to believe that securities are properly valued there are times when stocks may be temporary over- or under-valued. In these situations, investors can take advantage of the temporary mispricing and earn a short-term return.

- Investors are best served in these situations by utilizing an aggressive trading algorithm.

Portfolio Optimization: A quantitative portfolio manager is launching a new investment strategy to achieve a targeted rate of return. This manager utilizes a portfolio optimizer to determine the best way to achieve the desired portfolio return by minimizing portfolio risk. This results in a list of stock and share quantities that need to be bought for the portfolio. In these situations, investors can utilize a working order algorithm to balance market impact cost and timing risk and ensure consistency between the trading strategy and the investment objective.

- Investors are best served in these situations by utilizing a working-order algorithm that balances the trade-off between market impact cost and timing risk. The level of risk aversion for this algorithm will be selected so that it is consistent with the level of total portfolio risk and the expected Sharpe Ratio of the portfolio.

Portfolio Rebalance: A quantitative fund manager has determined that the expected return and risk for the portfolio has drifted away from targeted levels due to random market movement and noise. To bring the portfolio back in-line with expectations the manager rebalances the portfolio through a portfolio optimizer. This result in a basket of stock consisting of buys and sells. In these situations, investors can utilize a working order algorithm to balance market impact cost and timing risk and ensure consistency between the trading strategy and the investment objective.

- Investors are best served in these situations by utilizing a working-order algorithm that balances the trade-off between market impact cost and timing risk. Because the trade list will consist of buys and sells, the basket of stock achieves risk reduction through diversification and hedging (from buys and sells). This basket can be transacted in the market in a more passive manner than for the portfolio optimization example above because of the increased risk reduction of the list.

Sector Fund. A fund manager will often invest in a specified sector. This investment decision may be motivation may be based on a short-term or long-term view. Here, the manager may feel that the sector overall is a great investment opportunity, but has not uncovered any specific stock. Therefore, the manager will likely investor across all stocks in the sector or across a subset of stocks in the sector. It is

important to note here that the investment in the sector fund is to capture alpha from the sector. In these situations, the manager will likely trade aggressively if they have a short-term stock view to capture as much alpha as possible, or will trade passively if they have a long-term view and they do not want to alert the market to what they have uncovered.

- If the sector investment strategy is driven based on a short-term alpha view the manager is best served via an aggressive strategy, and using an arrival or POV algorithm.
- If the sector investment strategy is driven is based on a long-term alpha view the manager is best served via a passive strategy, and using a VWAP or a POV algorithm and accessing dark pools as well as lite venues.

Index Change. A change has been made to constitutes of the benchmark index for the manager. In this situation, the index manager will need to buy the stocks that are being added to the index and sell the stocks that are being deleted from the index, even if the manager does not have any short-term or long-term expectations for these stocks. An index manager needs to hold the same stocks as the underlying benchmark index and in the same dollar weights. In this situation, the index manager will utilize a back-loaded and or market on close strategy to minimize the market impact cost of the trade and achieve an average execution price as close to the official closing price as possible.

- Investors are best served utilizing a passive strategy and a Back-Loaded and/or a MOC algorithm.

Cash Inflow. A portfolio manager received an inflow of cash to invest in the market. In many times the manager will not have expectations for excess alpha in any stocks, because if they did, they would have likely already shifted investment dollars into these stocks. In this situation, managers will often allocate the cash inflow across the stocks already in the portfolio or a subset of these stocks. The manager will likely trade in a passive manner to minimize market impact cost.

- Investors are best served utilizing a passive strategy with a VWAP or POV algorithm.

Cash Redemption. Portfolio managers will, at times, receive a cash redemption call from investors. Here the investor is asking to sell stock so that they can receive the cash proceeds. If investors do not specify what stocks to sell, the portfolio manager may sell shares from all positions in the portfolio or from a subset of the positions in the portfolio. In these situations, the portfolio manager will trade in a passive manner to minimize market impact cost and achieve the highest prices for the positions that are sold.

- Investors are best served utilizing a passive strategy with a VWAP or POV algorithm.

Algorithmic Decision-Making Process

Portfolio managers who utilize algorithms to must be very proactive and must specify exactly how the order is to be transacted. Most importantly, portfolio managers need to ensure that the transaction strategy will be consistent with the investment objective of the fund.

The portfolio manager decisions, also known as the algorithm specifications, need to ensure that the order will be transacted in a manner that is consistent with the investment objective of the fund. For

example, if the portfolio manager uncovers a stock with a high short-term alpha estimate will need to trade the order in an aggressive manner to capture as much of the alpha as possible. In this case it would not be appropriate to trade the order in a passive manner because doing so may result in the stock increasing in price before the order is completed. Additionally, if a portfolio manager is trying to capture the closing price on the day because that is how the fund is being valued they will need to trade via a back-loaded or MOC strategy. It would not be appropriate for the manager to trade using a front-loaded strategy or high POV rate because this would result in the order being completed before the end of the day and would expose the fund to market risk.

This is accomplished via an algorithmic decision-making process that consists of portfolio manager decisions and order submission rules.

Portfolio Manager Decisions:

The portfolio manager needs to specify two important criteria for every trade. These are the macro strategy and the micro strategy of the trade and are as follows:

- **Macro Strategy.** Portfolio managers need to specify their macro trading decision. First, portfolio managers need to select the benchmark price, (e.g., open price, arrival price, VWAP price, closing price). Second, portfolio managers need to specify how to slice the over time (e.g., using a percentage of volume strategy or using a time slicing strategy). Third, portfolio managers need to specify how fast or how slow to trade the order. In many cases, the macro strategy is embedded in the select of the trading algorithm. The macro strategy is the strategy that provides the fund with the highest likelihood of achieving their investment objective based on expected market conditions. At times, the portfolio manager will specify the macro strategy via a quantitative process. For example, i) minimize the combination of market impact cost and price appreciation, ii) balance the trade-off between market impact and timing risk at a specified level of risk aversion, and iii) determine the strategy that provides the highest likelihood of price improvement.

- **Micro Strategy.** The micro strategy consists of specifying how the algorithm is to adapt to changing real-time market conditions such as price movement, increasing/decreasing volumes, as well as increasing/decreasing volatility. For example, if a manager has a buy order and price decreases during the day, the manager may decide to trade more aggressively to take advantage of the better market prices, or the manager may elect to trade more passively if she believes the favorable trend will continue throughout the day.

Order Submission Rules:

The next step in the process is that algorithm needs to define and specify the order submission rules to ensure that actual market trades are consistent with the Macro and Micro decisions specified by the investor. These decisions need to be made in real time, and by using real time data across all exchanges, venues, and dark pools. The order submission rules consist of the Limit Order Model (LOM) and the Smart Order Router (SOR) as are as follows:

- **Limit Order Model (LOM).** The limit order model determines the appropriate mix of limit orders and market orders for each order slice. It is essential that the portfolio manager reviews the limit order logic of the algorithms they employ to ensure these decisions are consistent with and adhere to the macro and micro decisions. Passive strategies will utilize a greater amount of limit orders and aggressive strategies will utilize a larger amount of market orders.

- **Smart Order Router (SOR).** The smart order router determines where to route a trade. The SOR will determine the destination with the highest probability of executing the limit order and will determine the venue with the best market price known as the National Best Bid and Offer (NBBO) for market orders. The SOR monitors real time data from exchange and venues, and will also assess activity in dark pool. The SOR is also tasked with evaluating trading quality to ensure that the manager's trading intentions are protected, and that valuable trading information is not being conveyed to the market. The SOR is tasked with determining the trading venue that will maximize the likelihood of achieving a fill or trade at the investor's desired price or better. It also provides whether the order should be routed to an exchange, to a displayed venue, or to a dark pool.

Transaction Cost Analysis (TCA)

Transaction Cost Analysis (TCA) provides investors, portfolio managers, traders, and brokers with the necessary information to specify a proper algorithmic trading strategy. TCA is comprised of pre-trade, intra-day, and post-trade analysis. Each is a very important part of the implementation phase of the investment cycle. These analytical models are provided to investors as either a web-based system or as a standalone system. Many funds have developed their own TCA analytics that are customized for their specific needs.

These are as follows:

Pre-Trade Analysis: Pre-trade analysis provides investors with the estimated trading costs of an order. This includes the expected market impact, price appreciation, and timing risk. Traders also use pre-trade analysis to evaluate different trading strategies and algorithms based on trading cost and risk. They also allow investors to incorporate their own market views and proprietary alpha forecasts directly into the analyses so that investors can develop a customized analysis for their specified order. Traders use these functions to perform single stock and portfolio multi-period trade schedule optimization.

- The goal of pre-trade TCA is to provide traders with the necessary information to select the most appropriate algorithm and strategy based on the underlying investment objectives of the fund.

Intra-Day Analysis: Intra-day analysis provides investors with the necessary real-time analytics to monitor transaction costs during trading. These models provide investors with point in time trading costs estimates (for executed shares) and the projected trading costs that will result from completing the order (for those shares that still need to be executed). This is accomplished by incorporating market momentum and actual market conditions (volume, volatility, and aggregated imbalances) directly into the analysis.

- The goal of Intra-Day analysis is to provide investors with the necessary information to determine when it is advantageous to take advantage of changing market conditions and favorable opportunities.

Post-Trade Analysis: Post-trade analysis serves as a report card on the trade. It provides investors with the cost of the trade and an evaluation of the trading performance. Post-trade analysis will include a cost comparison to various price benchmarks (e.g., Arrival, Open, VWAP, Close, T-1, and T+1) as will also compare actual costs to a pre-trade trading cost estimate for the selected strategy.

Post-trade analysis allows funds to determine how well their brokers and algorithms performed given actual market conditions. Investors can rank their brokers and their algorithms to determine which brokers and algorithms are adding value to the fund, and determine which algorithms and which brokers may be underperforming expectations and causing the fund to incur unnecessary higher trading costs. Investors can compute additional statistics related to the trade such as the relative performance measure (RPM) to help determine which brokers are adding value to the trading process and which brokers are causing funds to incur unnecessary trading costs. Customized post trade reports provide clients with the ability to sort, filter, and evaluate different trading situations right on their own desktop.

- The goal of Post-Trade analysis is to help investors measure trading costs and evaluate trade performance.
- It also helps investors determine which broker and which broker algorithms provide the best results based on order characteristics and market conditions.

Conclusions

This chapter provides students with an overview of the electronic and algorithmic trading environment. Ever since the inception of algorithmic trading, investors have been tasked with having to be much more proactive in their trading decision than ever before. Investors can no longer simple route an order to a broker for execution. Investors need to specify exact execution instructions to the algorithm which dictates exactly how and where the order is to be traded in the market. The most important part of these implementation or trading instructions is that they need to be specified so that they are consistent with the investment objective of the fund and the motivation behind the trade and investment decision. Students studying today's financial markets will without question encounter a market structure that is much different than in the past, and a market with a new set of nomenclature and decision rules.

Unfortunately, the academic theory has not kept up with the rapidly changing financial environment. The goal of this chapter was to provide students with an overview of the electronic and algorithmic trading environment, and how they can make the best possible trading decisions and ensure that there is consistency between the trading goal and the investment decision.

This chapter covered many different algorithmic trading topics, and all of which are extremely important for trading. Students can use this knowledge to make more informed implementation decisions for their fund, and this in turn, will provide improved portfolio performance. In this chapter, students were

introduced to different types of trading algorithms, transaction cost components, market impact, displayed markets and dark pools, and different venue pricing structures.

Most importantly, students were provided with insight into how to best make trading decisions based on the investment objective of the fund.

Students can utilize and employ the algorithmic decision-making process presented in this chapter to ensure that they are making the best possible trading decisions for fund. And the lessons learned from this chapter can be directly applied into the financial industry in a professional career.

Exercises:

1. The investment cycle consists of asset allocation, portfolio construction, implementation, and portfolio attribution. What is the primary role of the trader as part of the investment cycle?

2. In the financial industry, trading algorithms are often given fun and entertaining names. But unfortunately, these names do not often adequately describe what the algorithm is trying to accomplish or how it will trade. Describe the algorithmic classification scheme from this chapter and how it helps traders determine what the algorithms are trying to accomplish.

3. Describe each of the nine (9) transaction cost components from the chapter and provide an example of how they may arise during trading?

4. Describe a VWAP algorithm and a TWAP algorithm. How are they similar? How are they different?

5. What is a POV algorithm? What are the advantages of a POV algorithm compared to a VWAP algorithm? What are the disadvantages of a POV algorithm compared to a VWAP algorithm?

6. An index investor with a large order is trying to execute shares at the closing price on the day. From the list of algorithms in the section titled “Types of Trading Algorithms,” which algorithm would you select and why?

7. An active manager has determined that stock RLK is appropriately priced in the market but has a very strong long-term growth potential. The manager decided to purchase a large block of RLK shares. From the list of algorithms in the section titled “Types of Trading Algorithms,” which algorithm would you select and why?

8. Describe a Displayed “Lite” Venue. Describe a Dark Pool. Why would an investor choose to trade in a displayed market such as an exchange or ATS? Why would an investor choose to trade in a dark pool?

9. Describe each of the three venue pricing models: commission-based, maker-taker, inverted maker-take. Why would an investor choose to use a maker-taker venue? Why would an investor

choose to use an inverted maker-taker model? Why would an investor choose to use a commission-based model?

10. Describe each of the following algorithm order slicing strategies i) time-based, ii) volume-based, and iii) price-based.

Questions:

11. This chapter described two types of implementation tactics: agency execution and capital commitment (principal bid transaction).
    i. Briefly describe each.
    ii. If you are a trader who needs to transact at a known market price and is not allowed to incur any market risk during trading, which implementation tactic would you select and why?
    iii. If you are a trader who is looking for a low-cost commission fee trade and is comfortable trading in the market at market prices over the trading horizon, which implementation tactic would you accept and why?

12. This chapter described three types of trading algorithm categories: execution algorithms, profit-seeking algorithms, and high frequency trading algorithms.
    i. Which type of trading algorithm would you select if you are asked to execute a large block trade that was specified by your portfolio manager? Why?
    ii. Which type of algorithm would you select if your company has decided to start an electronic market making desk?
    iii. If you are a quantitative manager employing a statistical arbitrage and pairs trading algorithm, which type of algorithm would you select?

13. This chapter introduced an algorithmic decision-making process to assist investors select the execution algorithm and specify algorithmic parameters?
    i. What are the key decisions that need to be made by the portfolio manager? How does the investment decision of the fund manager effect these decisions?
    ii. What decisions are made by the algorithm? How does real-time market conditions effect how the algorithm will trade?

14. You are the portfolio manager of a large fund and concerned about recent high transactions costs due to delay cost and opportunity cost.
    i. How can a portfolio manager minimize the delay cost component?
    ii. How can a portfolio manager minimize the opportunity cost of a trade?

15. You are an index manager and need to purchase a large block order for a stock that is being added to your benchmark index at the end of the day.
    i. How would you purchase these shares if you do not have any expectations short-term movement of the stock? What would you select as your benchmark price?
    ii. The company that is going to be added to your benchmark index at the end of the day is going to hold a press conference in the afternoon to provide the market with an update

on company performance. You believe that the company is going to announce a new product that they have been working on and expect the market to react very favorably and you expect to see an increase in price. How would this information change how you will purchase shares? What are the risk associated with this decision?

16. You are an Active Manager who has uncovered a stock that is currently undervalued in the market and will likely increase to its fair value by the end of the day. Based on this research, you decide to purchase shares while the stock price in undervalued and then sell the shares after the market realizes the mispricing and the stock price increases to its fair-value price at the close.
    i. How would you execute these shares? Specify an algorithm that you would select to execute this order.
    ii. During the trading day, the price of this stock further decreases in price but your expectations remain the same. How would this change your investment and trading decision.

17. You are a Quantitative Manager who has just rebalanced the portfolio using quadratic optimization. The optimization process has provided a basket of stock consisting of both buy and sell orders.
    i. What type of algorithm would you use to execute this basket of stock?
    ii. If you are concerned about overall market risk during trading which risk management constraint would you specify: risk minimization or cash-balancing?
    iii. If the rebalance requires the proceeds of the sell orders to finance the buy orders, which risk management constraint would you specify: risk minimization or cash-balancing?

18. You are the portfolio manager of a large institution. Describe how your trading desk would utilize each of the following broker dealer trading desks:
    i. Cash Desk
    ii. Program Desk
    iii. Electronic Desk

19. You are a portfolio manager for a large fund. Your research team has uncovered a stock that has very strong long-term growth potential and is also under-valued in the market. Historically, this stock has exhibited short-term price momentum patterns. For example, if the price increases it is likely to continue to increase over the entire day. Based on this information, you decide to purchase a large block of these shares. As a portfolio manager, you want to make the best implementation decisions possible so to maximize portfolio performance. Therefore, you follow the algorithmic decision-making process from this chapter.
    i. As a portfolio manager, how would you specify your macro and micro decisions to execute this order?
    ii. If the stock has historically exhibited mean-reverting patters when an increase in stock price was followed by decrease in price shortly thereafter, how would this information change how you specify your macro and micro decisions?

20. In this chapter we decreased Transaction Cost Analysis and analytics. Describe how each of the following can be used during the implementation phase of the investment cycle?
    i. Pre-Trade Analysis
    ii. Intra-Day Analysis
    iii. Post-Trade Analysis

Keyword Definition:

Algorithmic Trading – Algorithmic trading is the computerized execution of financial instruments following a set of pre-specified trading rules and instructions. These instructions will specify how fast or slow to transact the order in the market, and at what prices, and trading venues. There are three different types of trading algorithms in the market: execution, profit-seeking, and high frequency trading (HFT). Execution algorithms are tasked with implementing and trading an order that was determined outside of the algorithms by a portfolio manager. A profit-seeking algorithm is an algorithm that makes both the investment decision (e.g., buy or sell stocks) based on quantitative models and the implementation decision on how to execute and implement the investment decision. An HFT algorithm will commonly be employed to act as an electronic market maker in stocks by providing the market with bid and ask prices throughout the day and helping to maintain a fair an orderly market.

Transaction Costs – Transaction costs are the unavoidable cost of doing business that is not incorporated into the price of the product or service. In economic terms, transaction costs are the dollars paid by buyers but not received by sellers, and the dollars paid by sellers but not received by buyers. In finance, transaction costs are the dollars paid above the decision price for buy orders and the dollar discount below the decision price for sell orders. In the trading environment, there are nine (9) transaction cost components incurred by investors that are not incorporated into the stock price at the time of the investment decision. These are: commission, fees and rebates, spreads, taxes, delay cost, price appreciation cost, market impact cost, timing risk and opportunity cost.

Market Impact – Market Impact is the movement in the price of the stock caused by the trade or order. Market impact consist of two components: temporary impact and permanent impact. Temporary impact is due to the liquidity demands of the investor where a buyer may need to offer the market a premium to attract additional sellers into the market and/or where a seller may need to discount the price of the stock to make the stock more attractive to purchase. Permanent impact is due to the information content of the trade. In this case, the market may perceive that the investor is buying stock because it is currently undervalued in the market or because the stock is expected to achieve excess future returns. Additionally, the market may perceive that the investor is selling stock because the stock price currently overvalued in the market or because the stock is expected to decline in price. Both cases would likely cause the market to reevaluate the fair value of the stock and we would see the price of the buy order increase and the price of the sell order decrease.

Algorithmic Decision-Making Process - The algorithmic decision-making process is used by investors (traders and portfolio manager) to assist with the selection and specification of algorithm and algorithmic trading parameters. Due to the changing financial landscape and shift to electronic markets,

investors need to be very proactive in the trading process and need to ensure that the implementation strategy will continuously be consistent with the investment objective of the fund. As part of the algorithmic decision-making process, investors need to make algorithmic trading decisions at the macro and micro level. Macro decisions specify how the algorithm is to trade over the day to ensure consistent with the investment objective of the fund, and micro decisions specify how the algorithm will adapt to real-time market conditions. In additional to the macro and micro rules, investors need to specify appropriate order submission rules including the limit order model (LOM) which determines the appropriate utilization of limit and market orders, and the smart order router (SOR) which determines which exchanges, venues, and dark pools to route the order for execution.