Cross Exchange Arbitrage Algorithm on High Frequency Trading Platform

Thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering

in

Computer Science and Engineering

Submitted By

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July 2015

CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "*Cross Exchange Arbitrage Algorithm in High Frequency Trading Platform*,", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Computer Science and Engineering* submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Parteek Bhatia and Vinay Arora and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Acknowledgement

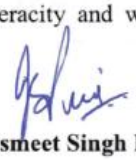
The successful completion of any task would be incomplete without acknowledging the people who made it possible and whose constant guidance and encouragement secured the success.

First of all I wish to acknowledge the benevolence of an omnipotent God who gave me strength and courage to overcome all obstacles and showed me the silver lining in the dark clouds. With the profound sense of gratitude and heartiest regard, I express my sincere feelings of indebtedness to my guide **Dr. Parteek Bhatia**, Assistant Professor, Computer Science and Engineering Department, Thapar University and **Vinay Arora**, Assistant Professor, Computer Science and Engineering Department, Thapar University for his positive attitude, excellent guidance, constant encouragement, invaluable cooperation, a generous attitude and above all his blessings. He has been a source of inspiration for me.

I am grateful to **Dr. Deepak Garg**, Head of Department and **Dr. Ashutosh Mishra**, P.G. Coordinator, Computer Science and Engineering Department, Thapar University for the motivation and inspiration for the completion of this thesis.

I will be failing in my duty if I do not express my gratitude to **Dr. S. S. Bhatia**, Senior Professor and Dean of Academics Affairs at the University, for making provisions of infrastructure such as library facilities, computer labs equipped with internet facility, immensely useful for the learners equip themselves with the latest in the field.

Last but not the least I would like to express my heartfelt thanks to my parents and my friends who with their thought provoking views, veracity and whole hearted cooperation helped me in doing this thesis.



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Abstract

From Last few years, financial markets have seen a large growth in number of trades' execution. This growth is due to high number of orders being generated in very less amount of time and this is not possible manually. Some algorithm is processing this large amount of orders without any human intervention. This is called Algorithmic Trading or Algo Trading. Algo Trading is just running an algorithm with some set of instructions to the system to process order and pick opportunities according to the given logic. NSE (National Stock Exchange) has reported tremendous growth of algo trades and this figure has reached almost to 40% of the daily trades. Algorithm can process order as fast as 100 – 150 microseconds on a good configured server with all the calculations. With more improvement in other technology, this speed is going to improve more. Human cannot virtually respond to these scenarios. Lots of financial houses are driving towards this automated algorithm trading. Algorithm is about how to process given information to improve the set of orders. Now a day, financial traders have reduced their profit per orders and started dealing very frequently accumulating smaller profits to have substantiated profits. But very less attempts are made into cross exchange trading. Algorithms performance suffers when it has to process data from two exchanges to send the order. Cross Exchange Algorithm Trading is the next big thing which will drive growth of overall financial markets all over the world. Besides Algorithm, we need more sophisticated computer network technology to improve the performance of sending an order. Cross Exchange Trading can be possible with few limitations but it has more profit due to difference in spread between same financial securities.

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Chapter 1 Introduction

A stock market index or stock index is a measurement of computed value of given section of the stock market. The value of stocks can be computed through various means (usually weighted average). It is used by financial managers and investors to give the description of market and comparing returns on various specific investments.

An index is constructed using mathematical formula for the given equity taking in mind many factors associated with it.

1.1. Different Types of Index

There are basically four types of indices which were and are presently being used across various stock exchanges. Each type of index has its own formula to calculate the price.

1.1.1. Price-weighted

Price-weighted index is calculated by adding all stocks in a given index and dividing it by total number of stocks, thus giving the average price of all stocks in the index. DJIA (Dow Jones Industrial Average) was calculated originally. But, there is one problem associated with it. If some stocks have higher price than others, than their price variation may have more influence over the stock index. If those expensive stocks have less economic impacts, this will give misleading impression of how particular market as a whole is behaving.

$$Index = \sum_{i=1}^{n} \frac{P_{it}}{D_t}$$

Where P_{it} - is the price of asset i at time t

D_t - Divisor at time t,

n – no. of securities in index.

1.1.2 Market-weighted

This is one of the famous and dominant methods for the calculation of stock indices. With this computational method, the company having $1 billion in stock will receive half weight than the company having $2 billion in stock reserves. This reflects company having $2 billion in stock reserves, the larger economic impact over the company having $1 billion in stock reserves. It seems correct that larger stock having more influence in moving the index than the change in value of stocks of smaller one. It is also called capitalization-weighted indices because of the term used to describe total value of company's stock (i.e. number of total shares times price of stock) is market capitalization. It is favorable in conditions where there is a need to reflect how a particular category of stocks is doing.

1.1.3. Equally-weighted

An equally-weighted index gives the same weight to each stock in the index calculation without regard to the price or market capitalization of the stocks. This type of index gives smaller capitalization stocks the same footing as large-cap stocks in their ability to influence changes in the index. It's sometimes argued that in a market-weighted index, very large companies have an exaggerated impact on the index value.

1.1.4. Fundamental weighting

This is one of the newest approaches in making of an index. Fundamental weighting includes referring to the underlying company's cash flow, book value, sales and other characteristics. Some stocks are overvalued or undervalued relative to their fundamental characteristics. This is what happened in first part of decade when stock prices of some high-tech companies soared beyond their fundamental properties like their sales, cash flow and underlying financial properties of their companies. This is where fundamental properties come into picture. This is one of the most complicated approach and decision to consider different important factors are also complicated.

1.2. Terminologies Related to Stock Market

There are few terms related to stock market which is necessary to understand the basics of financial trading. These are the basic building blocks for financial trading. Few of the terms are discussed in this section:

1.2.1 Futures

In finance, Future Contract (colloquially futures) is a contract between two parties to agree upon price with delivery today but transaction happening at future specified delivery date. Since, Futures are derivative product; contracts are negotiable at market place called future exchanges between the buyer and seller. The main purpose of contracts is to mitigate the risk of exchange rate or price movement.

1.2.2. Options

In finance, an option is a contract to buy or sell an asset on or before a certain future date which gives buyer the right but not the obligation. It is also a binding contract with terms and properties defined by the Exchange Board of the country (SEBI in India). But the advantage of trading with options is that you only pay initials a small amount to buy the contract at later stage, thus mitigating the risk involved. For e.g. you want to purchase some plot or land. But unfortunately, you do not have currently the cash to buy the given plot or land. You negotiate with owner a deal at Rs 10,00,000 with full payment in 2 months. The owner agrees and you both signed the agreement and pay upfront some money to secure the deal. Let this money be Rs 50,000.

Now two theoretical situations can arise:

1. It's discovered that National Highway is going to be build near the place and the price of property skyrocketed to Rs 25,00,000. Because of option contract, Owner is obligated to sell the property to you. So you stand to make a huge profit.

2. You discovered that this is the disputed property and market value of this property is Rs 3, 00,000. You are not obligated now to buy this property. You will obviously lose Rs 50,000 but the major loss is prevented. Thus mitigating the risk to some extent.

1.2.3 Intraday Trading

It is a speculation in securities, specifically to buy and sell the financial instruments within the same trading day. This is to close all the positions within the same trading day before market closes. Some traders are so strict that they have day trading part or component of a overall strategy. Some of the financial instruments which are traded in day-trading are Futures Contracts, Options, Stocks and Currencies. The cost of trading if intraday is less as compared to delivery trading as exchange and broker take less fees for the transaction with square off in intraday.

1.2.4. Delivery Trading

It takes approx 3 days to complete the transaction i.e. transferring of financial derivative to transfer into your demat account after the transaction. You can then sell it later at any point of your time. If not square off your position within a day trading, it is called delivery trading. The cost is more since broker's charge 0.2 – 0.4 % of the transaction, thus cutting into the profit.

1.2.5. Market Depth/Liquidity – Market Depth is ability of market to sustain the large market orders with little impact on the price of given security. This is considered by overall level and breadth of the open orders present in the market within an individual security.

Figure 1.1: MARKET DEPTH

1.3 Different Types of Order

Order is the structure of all information which client enters before sending to the exchange. This order is of various types. Each order has its own functionality and usability for particular scenarios. Following are few of the orders used by traders in their daily life trading.

1.3.1. Market Order

Market order is (buy or sell) order to be executed immediately at current satisfied market prices. Till market depth and sufficient quantity is present, market is supposed to be filled. These orders have more certain priority for trade than at which price order has to be filled. The order is filled at best prices available in market depth at that point of time. In fast-moving market like NSE, the price paid or received can vary from the last quoted price as price can change before it is entered. If quantity is not sufficient at some given price, then market can be split

across various multiple participants resulting in different prices for the same shares.

1.3.2. Limit Order

Limit Order is an order to sell security at same or more prices than a specified price and in case of buy, same or less than the specified price i.e. better in either direction. Limit Orders are used by trader to trade at the price they wish to rather than having certainty of trade execution. For e.g. If I want to buy some stock but I don't want to pay more than Rs 55 for it, then trader can put the limit order for that stock at Rs 55. Trade now will get executed at Rs 55 or less and vice versa for sell order.

1.3.3. IOC (Immediate or Cancel)

IOC stands for Immediate or Cancel. The purpose of this order is to grab the opportunity and trade at the given price if available. It can be partially filled if sufficient quantity is not available. Investors and Traders can specify about the duration of IOC orders but the duration in general is the moment order is fired, if not filled then canceled. It doesn't have to wait for any time. For e.g. I make and IOC buy order of XYZ Company at Rs 60.00 for 100 quantities and only 40 quantities is available at Rs 60.00. Then I will get 40 quantities and my order will be canceled and 60 quantities will remain unfulfilled.

1.3.4. Basket Order

It is a group order with combinations of many securities. It is mainly used by institutional investors and investment funds who deal with a large number of securities in certain proportions. As large amount of cash moves in and moves out of the fund, large basket order of securities has to be trade simultaneously, so that price movements of any security doesn't alter or affect the portfolio allocation. To be called basket order, it must include more than 15 securities.

1.3.5. FOK (Fill or Kill)

FOK stands for FILL or KILL. FOK order is similar to IOC order in many ways but both are different. FOK orders are used in securities which instruct brokerage for execution of the given transaction immediately like IOC but unlike IOC, it has to be traded completely or not at all. In IOC we allow partially trading of the given orders but in FOK, it has to be fully traded or not at all. The main purpose for this orders to get filled in its entirety or cancelled (killed) to ensure that the position is entered at a desired price.

1.3.6. Stop Loss

Stop Loss Orders are the orders in which we mention the upper and lower limit as defined limits for loss. Upper Limit is for Buy Order and Lower Limit is for Sell Orders mainly so that we couldn't buy the security more than our prescribed limit or sell the security less than our prescribed limit in order to contain our loss. We define some threshold percentage with which we calculate our upper and lower band price and this price is calculated with respect to 'Last Trade Price' for given last transactions. Average of Last Trade Price is given as limit Price for which our Threshold Percentage is applied.

1.4. Introduction to µTrade (mu-Trade) Platform

µTrade (mu-Trade) is a proprietary software of uTrade Solutions Pvt. Ltd. It is a capital markets trading Technology Company providing open source-based multi-asset trading platform, algorithms and analytics for global financial institutions including brokers, banks, exchanges, other financial institutions and their end customers globally. µTrade (mu-Trade) is a low latency infrastructure (~single digit microsecond latency from market data tick input to order out) that is live in several exchanges co-location facilities. It works across asset classes (Equities, Futures, Options, Currencies and Commodities) and supports extensive pre-trade and post-trade risk checks. Our algorithms incorporate:

- Arbitrage (Multi-leg equity/Future/Option, Spreader algorithms, Multi-exchange arbitrage, etc.)
- Market making (Based on risk, inventory, price movements of benchmarks, with comprehensive hedging choices)
- Execution (TWAP, VWAP, Smart Router, With Volume etc.)
- Quant based algorithms (Macro strategies, Pair Strategies etc.)
- API through which clients can code their own algorithms
- Excel based Trading -This platform also supports other features which can help one in trading in a planned manner,
- Highly flexible as well as customizable front end
- Risk Management
- Value added information (Option Calculator, Trade-wise Tracker, Live Greeks of Options, etc)
- Smart Order Books (individual for each strategy or can be combined)

1.4.1. Market Watch Options

- Particular security can be added by the user multiple times in the given market watch. The main purpose of this to pair one security with another in market watch.
- Any security can also be removed from the market watch using Delete key from keyboard or selecting remove Symbol from mouse. User can also remove multiple securities from the market watch.
- User can export to XLS any given security/contract list which is present in the market watch to CSV format and list can be created and modified easily from the Excel.
- The given CSV file can also be imported into market watch using the given options of importing the CSV file. CSV file should include Market(Exchange Name), Scrip Code (Unique Code for each security), Symbol (unique for each underlying security) and Symbol Name etc.

- There is also an option of feeding the live market feed to the Excel and using your own formulas and function calculations, you can feed back your order into the system. This Excel can be used as an independent application to our system.

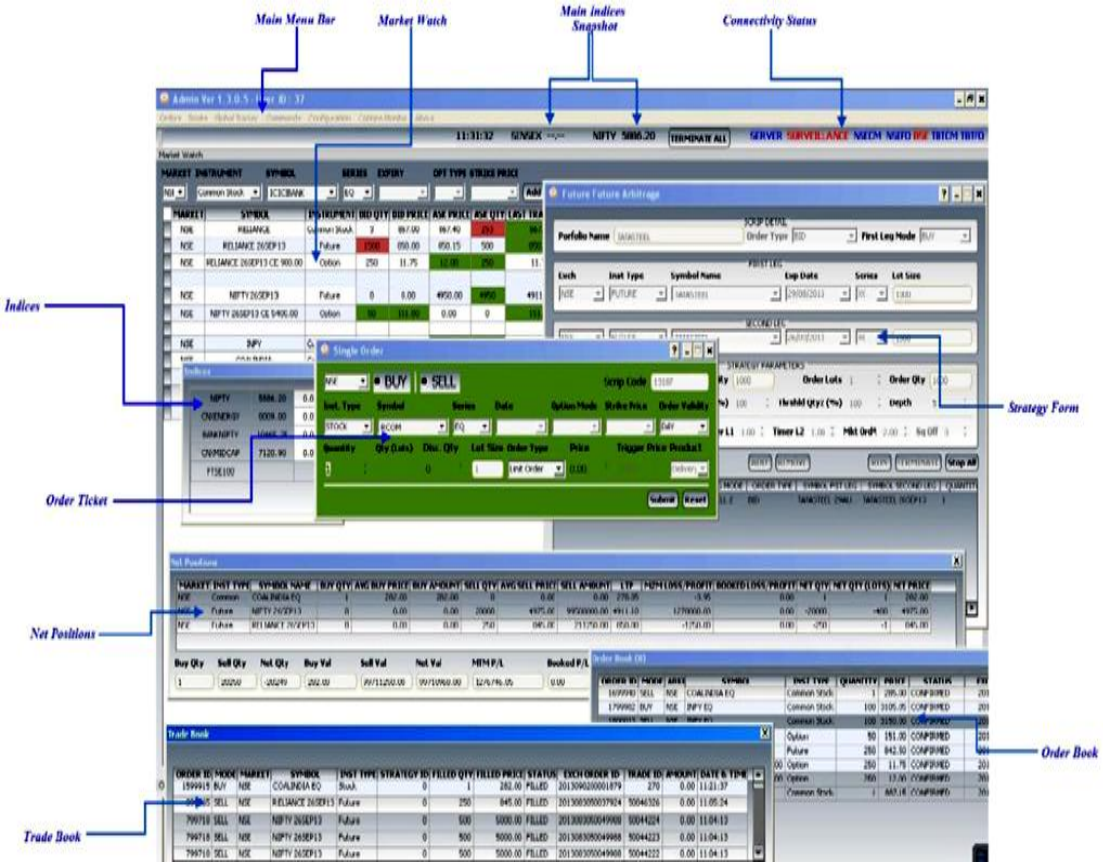


Figure 1.2: MUTRADE TRADING PLATFORM

1.4.2. Why do we need Algo Trading?

Before discussing about, why do we need Algo Trading, let us first understand the concept of Algo trading. Algo Trading (Algorithmic Trading) is basically a process of executing computer programmed set of instructions resulting in trade with speed not matched by the humans. It is absolutely impossible for human trader to execute trades with such precision and speed which system can perform

using particular algorithms. The defined set of instructions is based on price, quantity, time, historical data and other mathematical calculations.

Benefits of Algo Trading are as follows:

- Execution of Trades with utmost precision according to logic.
- Low Latency placing of orders with reacting to given scenario.
- Trades executing at given time to prevent any loss due to change in market scenario.
- Reduced Risks of manual error while placing orders.

The main part of today's algo trading is High Frequency Trading (HFT) which means that to accumulate the smaller profits over large number of execution of trades at extremely fast pace with respect to different markets and different decision parameters.

But many questions which arise in many people's mind are;

Is Algo Trading safe to use?

Can anyone misuse this platform by hacking into it?

Is it legal to use?

And many more myths are revolving around it!

To discuss this question, we can take example of the recent incident happened on 7th May, 2015. Some crisis was witnessed on Dalal Street when market (both BSE Sensex and NSE Nifty) fell nearly 2.5 % with touching even six and half months low and lowest in four months at end of the day. Everyone reportedly believing the reason for crash was due to strong selling by algo traders (mainly from algo trading platforms using HFT).

Second steepest correction is witnessed by the India Benchmark Indices of 2015, a fall of nearly 2.5% to 8100 levels of Nifty or nearly 220 index points. Selling pressure was to the tune of $1100 million. While these numbers speaks for themselves about Algo trading but the main question is, is it really any mistake of algorithm, Algo Trading platforms or Algo Traders?

The answer is No. The main reason behind crashing was not because of any misuse, misbehavior of any algorithm. It was because of some prevailing market scenarios like breaking news on taxing FII investors by government, Crude Prices moving higher and moving of funds from India to some Chinese IPO. What FII did was nothing illegal or misuse. They used Algo trading platforms in a way that can prevent them from having losses in phased manners. They used algorithms for better execution of their large basket orders. Algorithms only helped them in achieving better executions.

With this backdrop, I would like to discuss few myths revolving around Algo Trading. If we just compare algorithmic trading and other technological advances, we can actually see that most of the growth in trading volumes in the current market is just possible because of the improved technology helping in faster trading. It is an ongoing journey which will get improved and most of the growth has been done in this decade. It is only and only possible because of the technological advancement and next growth will be because of Algo Trading as this will help they trade more with lesser profits and combined profits to be larger. The automation in dissemination of market data and other relevant information by exchanges and trading participants; capturing and consolidation of market data from various exchanges and other sources of relevant information; making complex calculations on live and historic data, leading to trade decisions; trading and managing risk; lowering the latency and cost of trading and in automated algorithmic trading

Technology is highly efficient as compared to manual trading used by various market participants for fund managers (for maintaining Long Term Investments), High Frequency Traders – HFTs (who trade in such large volumes aggregating smaller profits from many trades), quant Algo Traders (using Historic data to predict future prices), exchanges (to liquidify the market) etc.
According to some estimates, over 75% of US equity trading and over 60% of UK trading can be accounted to algorithmic trading. These numbers are believed to be around 30%-45% in Indian markets.

1.4.3. Two myths revolving around Algorithmic trading

1.4.3.1 Myth 1: Market Failures are led by HFT firms

The Flash crash of 2010 and Knight Capital Loss in 2012 were because of HFT. But if we look back, when there was no HFT, there were also many ample crises of financial industries. For e.g. LTCM Crisis of 1998 and Sub-Prime crisis in 2007 where human error led to major crisis in the whole markets. The technology if managed and regulated well, then the probability and scale of such events can be reduced. Recent Airline crashes back to back still did not stopped people from travelling through air because there is a regulator who looks out for security of passengers and everything. Air travel brings lot of benefits to our economic growth to the region which is despite unfortunate crashes. Similarly, there is a regulator in financial technology that ensures that no misuse and proper Risk Management is there to ensure no such crisis could happen or probability for these could be reduced. HFT firms understand these risks and thus ensure that risk should be handled with more priority than the profits.

1.4.4. Myth 2: Institutional Investors are also not in competition with rise of technology in HFT firms

HFT firms are leading the race in use of technology to lower the latency in trading. It is because of their constant effort in Research and Development process; they have stepped up in technology value chain and enabled the Institutional Investors with smarter and efficient tools at more affordable prices. Some execution algorithms like VWAP, Smart Routers were not available with Institutional Investors a decade before now. It has been now made available to Institutional Investors and Retail Investors indirectly. So, We have to understand the main purpose of Algo Trading is not just to have more profits or crashing the market because of some faults or misuse but taking care of risks parameters more than the profit and to execute the algorithms in a more phased and efficient manner to get more profits out of each scenarios. Regulators also embrace this constructive technology which helps in growth of the businesses and economics

in financial markets. These advancements in technology also bring more transparency to the system.

1.5. Algorithmic Trading Strategies

Each strategy used some basic algorithm for the particular purpose. Algorithm is designed with taking in mind the usability and requirements for the strategy to execute. Following are the opportunities or way in which algorithmic trading is being used. So Let us discuss these in a brief manner one by one.

- Trend Following Strategies: Trend Strategies are based on price level movements, moving averages and other technical indicators. It does not get into any prediction or price forecasting. Trades are executed by algorithms depending on desirable trends which doesn't involve any predictive analysis complexity.

- Arbitrage of securities: This is one of the most famous in algo tradings as this helps arbitraging one security into same market or another markets. In this, buying a dual listed stock at lesser price from one market and selling it at some profit into another. This is risk-free arbitraging. Arbitrage happens between stocks in different exchanges or Future vs Stocks in same exchanges and Future vs Future in same as well as different exchanges. This differential in price and looking for profit opportunities is done by algorithm in very efficient manner.

- Index Fund Rebalancing: Index Fund has given periods to rebalance their holdings as par with prices of benchmark. This kind of strategies proves very profitable for algorithmic traders who capitalize trades with some difference in basis points profits depending upon number of stocks in it and algorithm makes sure of best prices with timely execution.

- Mathematical Model Based Strategies: Many mathematical based strategies are there which uses some combinations of options, Futures and its underlying

security to get positive and negative delta and maintaining total as zero bringing profit from in between the trades.

- Volume Weighted Average Price (VWAP): VWAP strategies are used to break the large order into smaller ones and trade it into smaller chunks to avoid making any difference in the market making more profit from average price which would have been otherwise if it had been a manual large chunk order. Algorithm takes care of these scenarios with much precision.

- Time Weighted Average Price: These strategies are similar to VWAP in a way that these also break large chunk into smaller one and divide each into time slots with start and end time. The main aim is to execute larger order close the average price resulting in more profit which could have been otherwise. Thus algorithm trading can help trade execution with minimal market impact on prices.

1.6. 'Cross Exchange Arbitrage Algorithm on High Frequency Trading Platform'

My research is on creating a **'Cross Exchange Arbitrage Algorithm on High Frequency Trading Platform'**. This strategy is built on API platform of μTrade. The strategy is presently being used by one of the client of the μTrade for trading between different exchanges to make out profit by picking the difference of price in same security maintaining position of the security even though between different exchanges. This Strategy can be used irrespective of exchanges, securities, price and quantity. It was created with the purpose of cross-exchange arbitrage but it can also be used with in the same exchange to do arbitrage between different securities having same underlying security. It can also be used for market making purpose in which liquidity is not much to create depths in safe manner making minor change in a strategy.

This strategy takes care of position being even by checking hedging quantity in the reference leg of the strategy which will be discussed in detail in Chapter – 3.

It was build taking in mind various risk factors involved in high frequency trading like to maintain states (mutex or semaphores) taking each order as individual. Few validations check are also in placed to validate between different parameters whose value is being taken from Front End form of strategy. Strategy Modification is also allowed while strategy is in running state i.e. we can change the value of any parameter suitable best for that present scenario prevailing in market to make out the maximum profit from each execution.

It also helps you in preventing loss while spikes in market i.e. immediate movement in price of stocks or index.

This strategy is also maintaining different behavior for call backs by different exchanges like SGX behaves different for cancelling of IOC order whereas NSE behaves in a different way and BSE behaves in a different way. So to maintain consistency of qty and price for the given security, Handling for different exchanges has been done.

This strategy was initially designed by taking in mind for the purpose of only cross exchange arbitrage in a given security, but over the time, the design was made more generic to help executing this for other purposes in an efficient manner, not affecting other strategies. So the most important aspect of this strategy is that it is designed in such a way that it can be used as various strategies for different purposes in an efficient manner. Now, it is being used for four different purposes.

Though we have to ignore some part of algorithm for one strategy or another but base for all the strategy is same. They all run with the same concept. It is a mixture of VWAP, Arbitrage and Market Making strategies.

Table. 1.1. Support of Strategies in Algorithm.

Name of Strategy	No. of Legs Required	Exchange Support	No of Exchanges Required
Market Making	1	3 (SGX,NSE,BSE)	1
Cross Arbitrage Trading	2	3 (SGX,NSE,BSE)	2
Future-Future Arbitrage	2	3 (SGX,NSE,BSE)	2
MSCI-Future Arbitrage	2	1 (SGX)	1

Chapter 2 Literature Survey

2.1 High Frequency Trading

High Frequency Trading has gained so much popularity in this decade and gained Its place and make an impactful foothold in the financial markets. This is because of increased participation by Financial Technology companies and startups in this area. The increased competition has created better atmosphere for the traders to use this technology for the trading purposes.

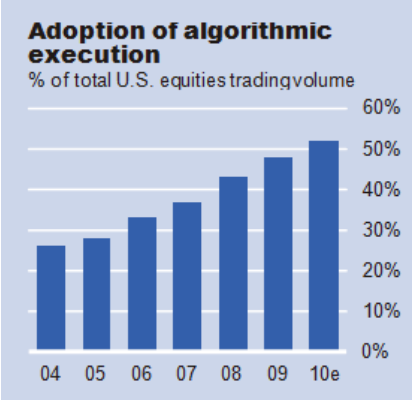


Figure 2.1: GROWTH IN ALGO TRADING

Because of constant improvement process by fintech companies, Indian bourses started growing comprehensively and even features in top 7 exchanges of the world (in no. of trades execution done in an exchange). It is estimated that number of trades executing in NSE through algo trading stands at 40% which is a good enough for the number of players present in market. More than 80% of Institutional trades (FIIs and Domestic Fund Managers) go through the algorithmic trading process. National Stock Exchange (NSE) has witnessed 25% more active investors than before. Retail participation in market stands at 2 crores whereas Institutional participation surging to new high of $300 billion with more than 465 FIIs investing in Indian markets.

Though, now a day, High Frequency Trading and Algo Trading is mixed in such a way that it becomes difficult to differentiate from each other. High Frequency

Traders and Algo Traders are complete different terms in the domain of financial technology but they are generally referred as same due to use of same technology for the trading of securities.

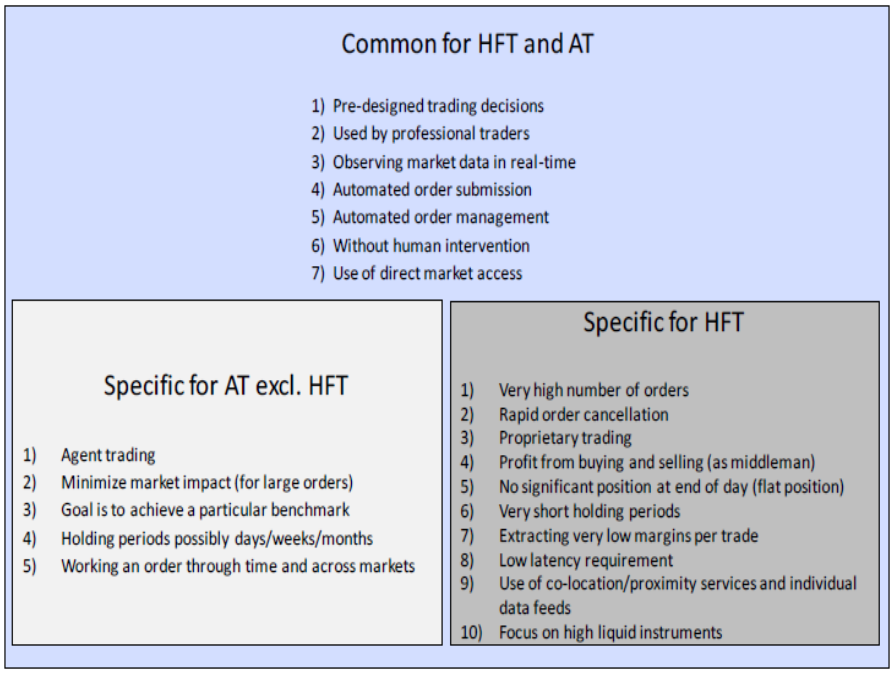


Figure 2.2: COMPARISON AND SIMILARITY of ALGO TRADING and HFT

Table. 2. 1 Difference Between ALGO TRADERS and HIGH FREQUENCY TRADERS

Sno.	High Frequency Traders	ALGO Traders
1.	High Frequency Traders believe in trading securities in large sum of quantity over period of time accumulating smaller profits whereas,	Algo Traders are usually there to reduce impact of carrying out large orders in the market with execution in phased manners.
2.	High Frequency Traders do not hold any long term positions whereas,	On the other hand, Algo Traders hold long term positions to accumulate profits.
3.	High Frequency traders generally end their day in a flat i.e. without carrying any positions to next business day,	Algo Traders generally carrying large Institutional Investor orders keep positions open for larger period of times as FII's are also not allowed to sell and buy security the same day.
4.	High Frequency Traders use Statistical arbitrage and generally use manifold portfolios for execution and also provide liquidity using liquid detection (market-making).	Algo Traders use VWAP and TWAP strategies to execute large orders in a phased manner to get minimal effect of market

2.2 Reasons for Using Algorithms in Trading

But for the sake of understanding, we will take High Frequency Trading and Algorithmic Trading as Electronic Trading done using various al algorithms in a controlled manner.

Cost of trading has reduced significantly because HFT's also provide more liquidity in a market resulting in more trade execution and automated executions result in lesser cost to the company. HFT algorithms can also help grab profit

opportunities in case of related assets like USD- INR, USD-Yen and INR-Yen and thus exploit the opportunity when available. Computers are way quicker than human in picking profit opportunities. We can observe market in real time and behave accordingly in an automated predefined manner for particular scenarios. Figure. 6 gives the detailed view of reason for using Algorithmic Trading in financial markets rather than manual trading.

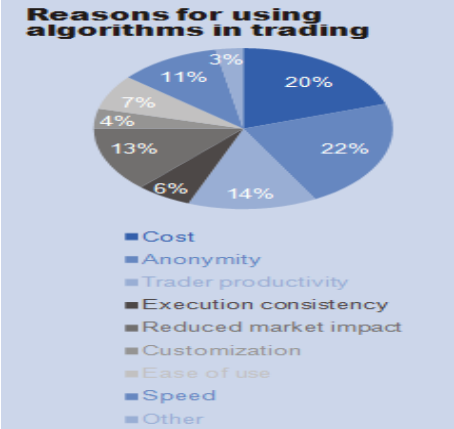


Figure 2.3: REASONS FOR USING ALGORITHM TRADING

All reasons described in Figure. 6 are main reasons for using algorithm in trading. Cost has been reduced drastically and the main benefit which it provided is Speed. Let us say, my algorithm is about taking spread of 3 Rs in market between two futures securities.

So I will have to wait till this spread is available in market to trade my order. If I am buying 2nd Future and Selling 1st Future. Then my Spread (Profit) becomes:

2nd Future Sell – 1st Future Buy

Now computer as per my algorithm will take hardly 2 microseconds to do calculation and can probably throw the order in roughly 10 microseconds, whereas human mind cannot react with such speed. It takes 200 microseconds to get back the call back from exchange and system will probably grab the profit in another 200 microseconds sending second order. So in 400 microseconds, system

will come out of this iteration and will probably start with another whereas human mind cannot respond even in 1 millisecond (1000 microseconds). Sending order at faster speed makes your order on higher priority than order to get trade with. And system can perform at this frequency with consistency whereas human mind can vary with many external factors.

2.3 Related Concepts

Some of the strategies which as a legacy is followed to design the new algorithm and concept of these strategies which are already being run by the client on different exchanges for their purpose.

2.3.1 Market Making - Market Making term is used for strategies involved in quoting simultaneously sells and buys order for security (financial instrument) in order to gain profit from the bid-ask spread. BSE even gave some subsidy/incentives to the trader doing market making in the options so that some liquidity comes into those security for trading. Bid Price is actually the price which market maker is willing to pay for buying the security and Ask Price is price at which market maker is willing to sell the security. Price can be dependent on many factors 'BID, ASK, BID I.V, LTP etc. Generally Price different is taken into account while doing market making as Buy/Sell orders should be relevant to some reference product for calculation. Now user needs to define the spread it needs and software can calculate depending upon percentage or absolute value given and Reference Instrument needs to be same as Order Instrument to get price difference less than the total spread required and it makes the spread between them near to the given value.

2.3.2. Future-Future

This arbitrage quote model of Future-Future is used for rollover of positions of future across different expiries of any underlying security. The main logic for these strategies is to have same underlying but Futures security with different expiries. These strategies are basically run with VWAP algorithms i.e. order quantity is break into volume to be averagely distributed. The main purpose of

this strategy is to gain spread using difference in prices of two futures. Now if they do not hedge their order in another security, the profit cannot be gained. So, they concept of threshold qty comes into place which states that given quantity has to be available in the second future for first future to get trade. So we do not believe in generating bid for the price till sufficient amount of quantity is already available with the system. Since, there is enough liquidity in some exchanges for futures, there is lot of movements and your system will continue changing the price of the security to match with latest ongoing spread but sometimes the change is so minimal that it is not advisable to change with that as this will eat resources and the tap limit in case of NSE orders. So there is certain amount by which difference, we have to avoid putting order into the market. For e.g. Price is currently at Rs 900.00 and due to change in price in reference instrument, the price has changed now to the 900.05 and then again back to 900.00. So there is no point in changing price for 5 paisa. So generally a certain parameter is given to avoid going for particular changes in prices. So for that particular change in prices with respect to old price of instrument, we do not change the price of our security.

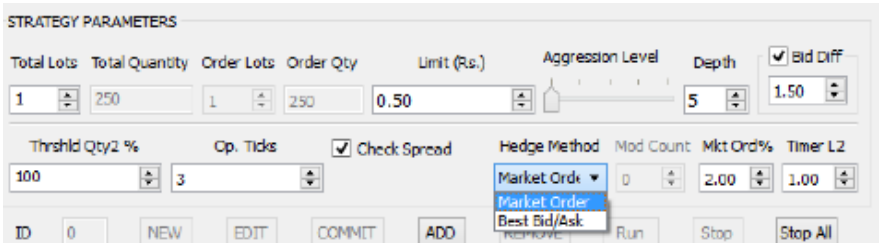


Figure 2.4: FUTURE-FUTURE STRATERGY PARAMETERS

Now it is not guaranteed that you will always get the required order or price at which our system saw. It is estimated most system with calculations take 200 microseconds and above to throw order or there is coincidentally some order at the same price which gets traded, so there is a chance of slippage in these cases which can cause some serious loss to the client. So what is suggested is the combination of some delay and bid difference to be in place. Now if my buy order is Rs 900 and I am here to sell my security with spread of Rs 3 and for that I need the buyer at Rs 901, then probably, I have to wait for the moment to get back the

price at Rs 901. And if Buyer comes at Rs 901 and I tried for that order and that is taken by someone else before I could get. And I pick Rs 900 order, and then I can get the slippage of Rs 1 here. The point is not of Rs 1 here as the overall loss is much more since one lot is of multiple quantities depending upon the security and the number of lot getting traded at the give point of time also comes into factor.

So we have to look if certain difference is there, we will throw our order only in that condition mitigating our risk to minimal. Though we are here for making profit but not at the cost of risk. We have to take certain measures to avoid any loss making scenario and if slippage comes, then we prefer to have some delay so that this is not repeated again. Market Depth changes before even we blink our eye so delay of 500 milliseconds even does the enough.

2.4 Basic Exchange Behaviors

Exchanges has some common behaviors with respect to the orders but there are few scenarios in which each exchange handle it according to its own rules and specifications. Following are discussed some behaviors.

Table 2.2. Exchange Call Back Confirmations

Confirmation	Behavior	Reason
Confirmed	**Price, qty is visible in depth**	**Exchange Accepted Order**
Replaced	**Price, qty is modified at exchange**	**User modified value of price, qty and accepted by exchange**

Canceled	**Price, qty is removed from order depth**	**User Canceled it's order and accepted by exchange**
IOC Canceled	**IOC order is Canceled**	**Exchange doesn't trade this order and canceled the remaining quantity**
Filled	**Trade is executed**	**Your order is matched with some other order to get trade**
Partial Filled	**Price and Remaining quantity will still be available in depth**	**Order is partially filled and remaining quantity can still be traded.**
Replace Rejected	**Order is not replaced with new price, qty.**	**Tried Replacing previous order but could not replaced it for some reason**
Cancel Rejected	**Order is not canceled**	**Tried Canceling the order but exchange rejected due to some reason.**
New Reject	**New Order is not**	**Exchange is not**

	accepted at exchange	**connected or not opened**
Frozen	**Order is not accepted at exchange**	**Order has not feed correct parameters.**

- Confirmed – When we send our new order to the exchange, exchange checks for some parameter involved with the order like order validity (Day, IOC), product type (Delivery, Intraday), price (if in circuit range), qty (if in circuit range) are few of the parameters checked by exchange and then it is accepted and send into order depth to check if it can be traded or not.
- Replaced – If user wants to modify its order to some different price or qty or both, then it can modify the order and upon its validation, exchange send the call back for replacing of order which signify that exchange has accepted the modification in the order.
- Canceled – If user changes his/her mind about the order and wants to cancel it, then upon the validations, exchange cancels the order and sends back confirmation to reply in affirmation.
- IOC Canceled – IOC orders have the property that if not traded, then they get canceled. Few Exchanges send IOC Canceled, some Canceled and some New Reject. So depending upon the exchange, behavior has to be handled. Exchange send back the order in different format of FIX but has some fixed protocols for the respective exchange. We can look into it to get IOC Canceled.
- Filled – If the accepted order at exchange get fully traded, then exchange reply back to inform us about the scenario.
- Partial Fill – If some of the quantities is traded and remaining quantities are yet unfilled, then exchange inform us after each partial trade of the order to help us.

- Replace Rejected – If user trying modifying an order with different permutation of price, qty, and order get traded or due to some undefined parameters by the user, then exchange send rejection message to inform the user about the behavior.
- Cancel Rejected – Similar to Replace Rejected, this rejection message is sent by exchange to inform us about the order not canceled. Main reason for this order is if order is already traded before cancel request is received by the exchange.
- New Reject – New Reject is sent by exchange when there is some undue behavior by order to the exchange and exchange rejects that order from getting into order book. Like if we try to place some order into the exchange before or after its opening time, then it sent back the rejection message with some error code relative to that scenario.
- Frozen – Frozen Confirmation is sent when an order is trying to place into market with some invalid parameters, not allowed for the client, price is 0, quantity is 0, etc.

Chapter 3 Research Problems

3.1. Problem Statement

With so much changes came with technological advancement in technology in financial markets, the next growth engine is said to be with algorithmic trading in this industry. With overall trading rising to an all time high, with statistical figure going to around 7.5 million trades with volume of 865 million shares. Total value exchanging hands is around Rs 16,000 crores in a single day. So we can imagine looking at this huge number that from where these trades happening. Around 40% of these trades are happening through algorithmic trading through HFT (High Frequency Trading Platform). Now more and more financial houses are coming for these platforms for their trading.

Now with the advent of HFT and other highly efficient algorithms, those financial companies are making more and more profit in a sophisticated way with lesser risk. So there is a great opportunity in developing an algorithm for this purpose. But the problem is that, most people are still attached with one exchange for the trading. Less than 1% of those, who use HFT platforms for the trading purpose are actually using cross exchange trading which have lot of scope to cut profit from either way looking into spread. More profit can be gained if there is more spread. Since we all know that lots of financial securities are there which are present in more than one market-exchanges like Reliance, SBI being present in both NSE and BSE whereas NIFTY index is present both in SGX and NSE. There is lot of symbols containing into many exchanges giving chance to arbitrageurs for extracting profit with some sophisticated algorithm playing in both the exchanges.

So with the use of HFT and some sophisticated algorithm for this purpose, we can use it to trade with more stability, discipline and efficiently than what human

trader can does manually. So algorithm trading is what is described as the future of financial trading. You cannot beat the system's performance.

3.2. Research Gaps

While many are in place but not many can deal with cross exchange trading. Since different exchanges need different behavior for handling, not all can do it with low latency. The other problem is various factors which should be handled are tick size for particular instrument in particular exchange. Difference of currency can also cause a little hindrance in doing trading for the given instrument. Many approaches have been made to create cross exchange algorithm but they do not serve purpose because of latency and not able to trade at the given price resulting in slippage on actual profit, not serving the purpose having double cost involves.

Another gap remained in strategy is that they cannot use it for another purpose. There are strategies individual for each purpose like market making strategies do not o arbitrage trading whereas arbitrage trading strategies do not believe in market making. What if both purposes could be solved with one strategy and it could behave depending upon the prevailing market behaviors on its own.

3.3. Research Objectives

In light of some of the discussed research gaps, some following objectives have been formulated.

- Algorithm in a way which could help cross exchange trading without any latency in both the exchanges
- Arbitrage could happen between different futures for same security.
- Can be comparable with legacy strategies with better performance in term of profits and efficiency with risk mitigation and trade execution.
- If spread is not favorable and depths can be created to allow arbitraging of these strategies with the help of market making

3.4. Research Methodology

Since lot of money is riding here, we have to be cautious in each and every step. Profit is the purpose but not at the cost of any risk. It has to be balanced in every step to prevent any major loss to the client. We also have to provide easy way of trading between different exchanges. So it has to be compared with other strategies for each purpose like Market Making and Future-Future. This strategy has to be designed with compatible with muTrade Trading platform. Test-cases have to be designed which could cover all negative and corner scenarios with precision. Main aim is to execute full iteration in a span of 500 microseconds at maximum as latency going to play an important part to make strategy useful for the algo traders of financial houses.

Chapter – 4 Implementations

4.1. Initial Design of Algorithm

Algorithm was initially designed to make cross exchange arbitrage possible over High frequency trading platform. The design was to make sure it doesn't lag while placing order at both exchanges. To develop the algorithm, we took in mind the SGX and NSE exchange for the trading. Both have common future Nifty which could be arbitraged depending upon the spread.

So algorithm logic was first created.

- Need to select two symbols from both the exchanges. One will be called order Instrument while other as Reference Instrument.
- Bidding will take place in Order Instrument while Hedging/Square Off will be done in reference Instrument.
- Bidding will happen with respect to prices at reference Instrument similar with the order mode i.e. BUY or SELL.
- Bidding will be done correspondingly in both the modes.
- Hedging Order will be only on one side depending upon calculations.
- Now it is not necessary for lots size to be same for both the future security, so we will take hedging parameter in terms of quantity which will be converted into lots accordingly.
- We need some parameter irrespective of currency and precision to be there for profit in first leg and slippage while doing hedging in reference instrument. So we will deal with tick size which is converted into money terms with respect to each instrument. Since 1 tick Size of Nifty Futures in NSE is of Rs 0.05 while USDINR currency Future has tick size of Rs 0.0025. So it is easy to deal in tick size than absolute value terms.
- Timer to increase aggressiveness in price for trading the order in reference leg. If continued with this aggressiveness, we will have another timer after

which it will over ride the previous timer and place the best order in the market if still not traded.

These were some of the basic implementation details of the algorithm. So the flow for this algorithm is as below.

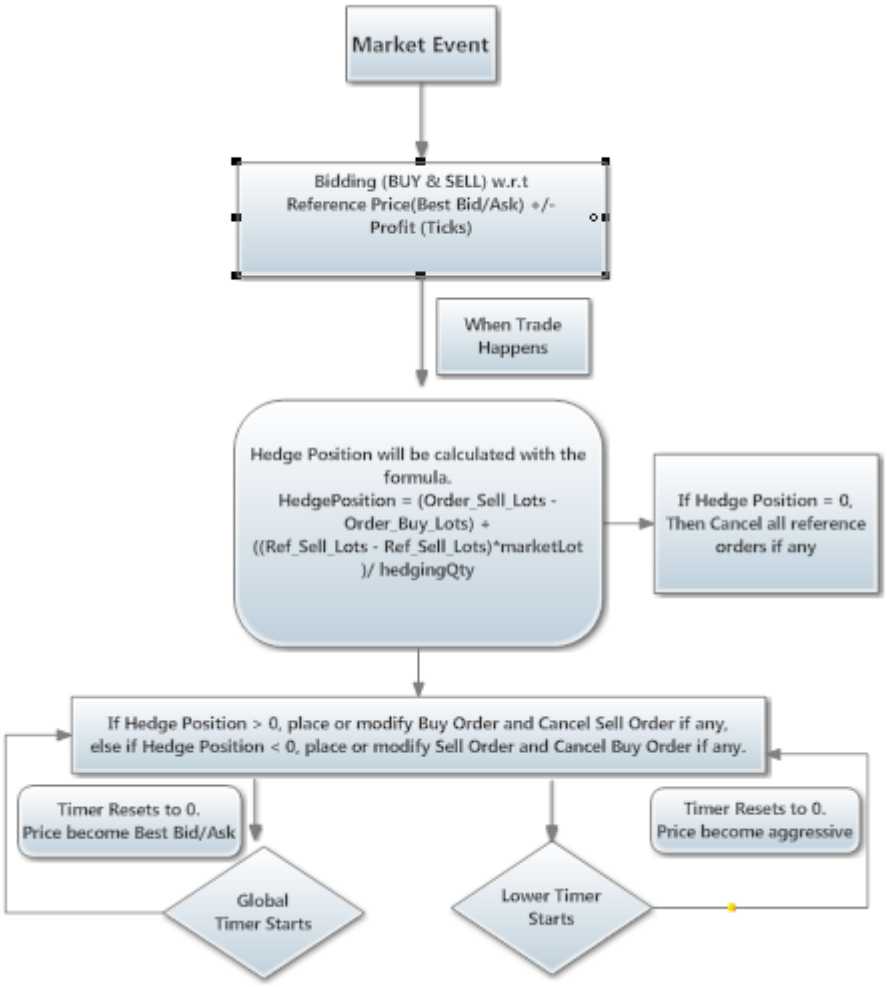


Figure 4.1: FLOW CHART OF ALGORITHM

Now the basic algorithm was ready for trading. To understand it with more clarity, we will take examples.

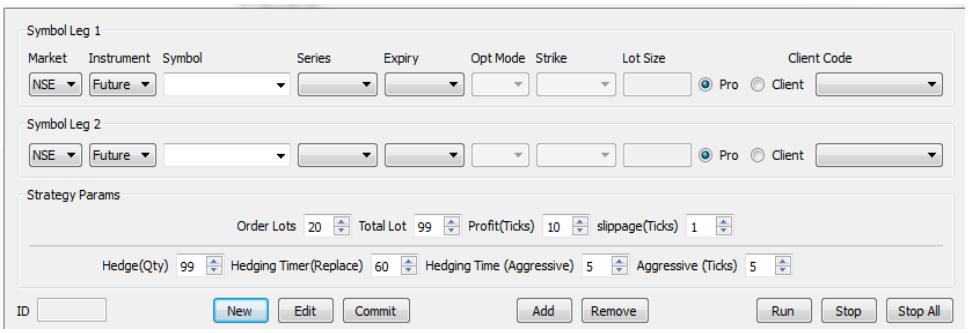


Figure 4.2: STRATEGY PARAMETERS FOR INITIAL DESIGN

For example, we are taking one instrument as NSE Nifty and another as SGX Nifty. They both have prices closer to each other but due to little difference in prices, we can easily gain spread to trade.

Table 4.1 : DEPTH OF NSE NIFTY

Buy Price	Buy Quantity	Sell Price	Sell Quantity
8346.00	100	8346.55	100
8345.15	25	8346.65	75
8345.10	500	8346.70	25
8345.05	50	8346.75	50
8345.00	4925	8346.85	100

Now, we will be looking into depth, and will take 8346.00 for our Buy order and 8346.55 for our sell order. So these will be our reference prices. Now we will take 10 ticks as profit for order Instrument

Now we have to see that 1 tick in SGX Nifty = 0.50 Rs.

So Buy Order Price = Rs 8346.00 - 10*0.50 = Rs 8341.00

And Sell Order Price = Rs 8346.55 – 10*0.50 = Rs 8351.55

Now Sell price is not in modulus with ticks. So we will convert into tick size aggressively.

Now Sell Order Price will be equal to 8351.55 + (0.50 - (8351.55%0.50))

= Rs 8352.00

Now let us assume, our order quantity is 10 lots for both sides. And 5 Buy Order get Traded.

Now hedging comes into factor. Now we have to take care of 1 thing in mind that size of 1 lot of SGX Nifty is of 100 quantity where as in NSE Nifty , it is of 25 Quantity. According to formulas, setting price and quantity, 1SGX lot = 130 quantity of NSE Nifty due to vary in prices.

So Taking 130 quantity as Hedging quantity, we will order (5*130/25) = 26. So we will place hedge order in NSE for 26 lots. Taking defensive ticks as 5, so now Price is Rs 8341.00 + 5*0.05 = Rs 8341.25

If in between 3 SGX Sell order lots are traded, then we will cancel some of our NSE orders. Here we will calculate Hedge Position

HedgePosition = (Order_Sell_Lots – Order_Buy_Lots) +

((Ref_Sell_Lots – Ref_Sell_Lots)*marketLot)/ hedgingQty

HedgePosition = (3-5) = -2

So we will now be replacing our previous order and it will now be of

2*130/25 = 10.4 (10)

Now we reduce our quantity from 26 to 10. In this way, whole calculation will revolve.

There are actually liquidity problems in another exchange like SGX Nifty has little depth. We have to do market making in this scenario to do arbitraging, since without any other orders in the depth, we cannot take out any profit. So first step is to check if order Depth for First Instrument is empty for particular order mode. We provide both buy and sell order to take place at the same time. If order Mode

is Empty, then create multiple instances of the strategy and run it to create intense order depth. The price will now be in your control to move upwards or downwards. Take profit with easy differences so that people could look into spread and start trading. Take out the initial orders to create liquidity which will help people continue trading in particular securities. Once enough depth is created, take out your order and start with profits. But after running it on demo platforms for few days, we got few problems which should be addressed and this was mainly the hindrances for cross exchange trading.

4.2. Improved Implementation Design

There were some of the problems which were not taken into consideration while designing an algorithm in an initial phase. Following are the problems.

- No point in making both sides order if is getting profit from one side and loss from another.
- What if not enough quantity is available in reference instrument? Hedging could not be done and position could differ.
- If someone at reference leg ordered at higher price than already best, we could start our iteration at more prices could result in loss or lesser profit while doing hedging.
- What if we are getting easily traded in our order instrument and our profit is not sufficient, we have to have to some mechanism to increase profit on its own.

So major changes have been done into the algorithm to handle some of the issues prevailing in previous algorithm. If one order mode is making profit and other are at loss, we could provide them with the options of trading in only one order mode than both sides which can help them making more profits. So generalized behavior is created that we will continue processing other modes with default values i.e. 0 for Traded Lots, Order Lots in case we selected one order mode. This helps us executing every other trade as expected.

- Now important part of arbitraging has been squaring off the order or hedging in reference leg, to mitigate the risk. But what if could not hedge our order in the reference leg, we can never make out the profit. So important thing has been to provide one parameter which will tell us to how much threshold quantity should be available in reference leg. Instead of taking absolute value, percentage value is much generalized as used do not have to think of cross multiplications.

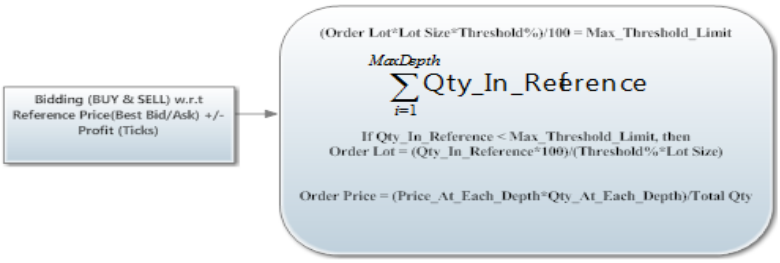


Figure 4.3: THRESHOLD LIMIT CHECK IN ALGORITHM

Now 150% means that if you have the order lot of 5 with each lot containing 100 quantities, then 150*5*100/100 = 750 quantities has to be available in reference leg. Now question arises 750 quantity has to be available at which depth. Should it be available at first, second, third or overall. So we will also provide parameter taking depth as a value. Now we will look into that much depth if this quantity is available. We can continue with this order if that much quantity is present in our depth.

If that much quantity is not available in our reference leg, we will take total quantity present in depth and will do reverse calculation to calculate order lots sufficient for order Instrument to execute the iteration.

For e.g. instead of 750 quantities, we could find only 500 quantities in our reference leg, then formula to calculate will be:

$$\text{Order Lot} = (500 * 100/ (150 * \text{Lot\_Size}))$$

$$= (500*100/ (150*100))$$

$$=3.33 \cong (3 \text{ Lots})$$

So In this way, we could hedge in a safely manner. But now price is not just dependent upon one depth. Since we are looking into multiple depths, then we should refer to weighted average price accordingly to the quantity available in each depth. One more check is there to prevent position form piling up is that we give them the right to input the amount of lots which can be unhedged at any single point of time. No more order lot will be send if unhedge Position reaches that point. Bidding will restore again only after the point when position gets even. Order Lot is also selected with respect to maximum unhedge position.

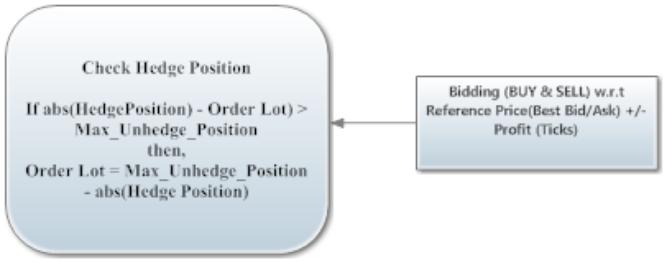


Figure 4.4: VALIDATE MAX UNHEDGE POSITION

- Now, there is a chance that our price could be extremely higher in particular order mode.

  For e.g. If Best Bid order in Buy Depth is placed at 8050.00 and our calculated price comes out at 8100.00. Now question arises why should we buy at 8100.00 if next buyer is at 8050.00. This could drive market towards buyer side spoiling our profits from sell side. So to maintain a little consistency, we insist if we are becoming best in the market then we should have to best by one tick only i.e. we will place our buy order at 8050.50 instead of 8100.00 and can hope to get more profit we are expecting gaining more spread.

Figure 4.5: HOP PROFIT

- Now we are giving hop profit parameter which says that after given amount of lots traded without slippage, the profit will be increased by some given ticks. So this actually helps us maintaining the trend going in market, that if we could pick more spreads, then it will be useful for them to continue increasing it.

  Below is the complete set of parameters which are provided to the client for the purpose.

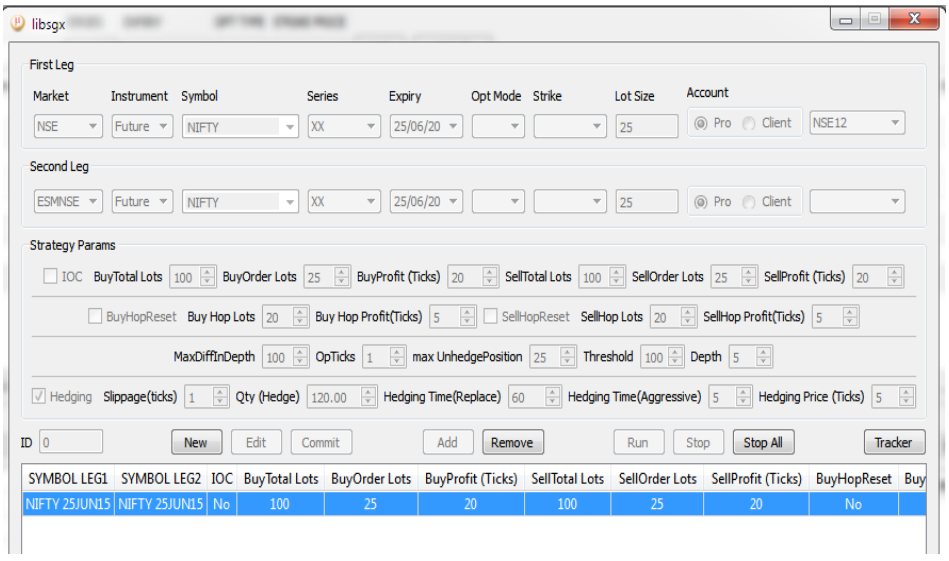


Figure 4.6: STRATEGY PARAMETERS OF ALGORITHM

4.3. Overcoming the Limitations of Cross Exchange Trading

Now Cross Exchange has some limitations which discouraged traders to do trading. Some of the limitations are hardware limitation which says that your server cannot be collocated at two locations. So you have to manage with one server. Different call back behavior for different scenarios also distracts traders. Different values to trade in required more calculation to and from INR. So to avoid all these limitations, we create a mechanism to handle all the issues at our end.

- Different Values for each symbol – It has different market lot, different tick size, different last close price etc. If we try to access both values at run time, it can cause us to lose 200 milliseconds from server to exchange to get these values. So we create database at our end having all the values from before and initialize it in our local variables while constructing an object help us in prevent eating any run time.

  We create instrument beforehand storing all the values inside the object to help us get it at run time in no time.
- Different behavior of exchanges – Currently, NSE runs on TBT which says that it will provide us the data tick by tick even before people in market get access while other market still are not able to. So while selecting an exchange from the form, we cannot restrict them from choosing any exchange. So we take parameter in Instrument to get if selected exchange is NSE, we will be using TBT data because exchange has to be told from before subscribing for the given symbol. Another behavior is that call backs from exchange as discussed in 2.4 can be different. For e.g. on IOC order, SGX sends back New Reject if it is not traded while NSE sends back Canceled and BSE sends back IOC canceled. If we try to replace an order in SGX and is satisfying trade condition, SGX sends back Filled and then Replace Rejected for these cases. So to handle all the call backs, we created a uniform Event Handler for the exchanges and maintain each order with respect to exchange.

Wrapper for each exchange is created for particular order to make its behavior uniform with respect to other exchanges. Exchange specific handling has to be done in the algorithm.

We cannot afford losing our time in creating full structure for order which has to be created by us respectively for each exchange in run time. So instead we create our orders from before and just modify it when opportunity arises and fill up the price and quantity which is only decided at the end. We create our next order when order is sent, since we have some window here to do these things till next call back comes. So we create the buffer and store it in it.

Chapter -5 Testing and Results

5.1. Testing Environment

Testing plays the most important part in case of algorithmic trading since lot of money is riding on these algorithms. Small mistake could cause client to have losses running in few lakhs.

Testing Environment used to test this strategy is ESMNSE exchange market which is created by the muTrade Pvt. Ltd. for testing purposes. NSE Test market is used for another reference leg which is given by NSE on rental basis to test our strategies before making live. These strategies on running on both platforms at the same time yielding excellent results.

We could match positions and risk mitigation was also properly handled important in case of algorithmic trading.

Load Testing was also performed resulting in good results. Load Testing yields that we can run 650 instances at the same time without any much load on the server.

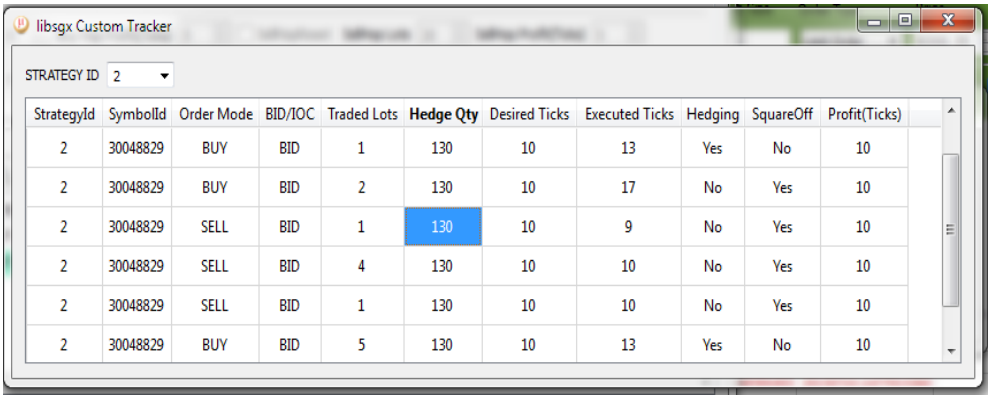
In terms of figures, we could send our order after getting market event (any event for which we have subscribed to the exchange) to get out of the system for exchange is approximately 200 microseconds on an average server. This time could further be reduced on the live server used by clients because those are heavily configured. In live that time came out to be 60 microseconds. Travelling time depends upon the server location from the exchange.

```
18:10:14.918394 |  Value of Threshold Qty becomes after calculation 0
18:10:14.918402 |  Hedge Pos is: 0
18:10:14.918406 |  Value of Threshold Qty becomes after calculation 650
18:10:14.918411 |  Place Order is set to True coz Qty is Diff 125
18:10:14.918416 |  Final Sell Qty is: 125
18:10:14.918419 |  Final Sell Price is: 839990
18:10:14.918838 |  Qty for Req New Order is 125
18:10:14.918848 |  Price for Req New Order is 839990
18:10:14.918898 |  Sell Order placed
```

Figure 5.1: LATENCY TIMESTAMP

We could see here that we started this iteration at 18:10:14.918394 and ended at 18:10:14.918898 making 200 microseconds to send the order with all the calculations. This time has come with print enabled. As we all know writing in a file and calculating time stamp is a costly operation, this time can further be reduced by disabling prints and time can come to 135 microseconds.

Now Performance on one side is good but performance doesn't till it makes any good execution result. Below figure is the live market result from client's system.



StrategyId	SymbolId	Order Mode	BID/IOC	Traded Lots	Hedge Qty	Desired Ticks	Executed Ticks	Hedging	SquareOff	Profit(Ticks)
2	30048829	BUY	BID	1	130	10	13	Yes	No	10
2	30048829	BUY	BID	2	130	10	17	No	Yes	10
2	30048829	SELL	BID	1	130	10	9	No	Yes	10
2	30048829	SELL	BID	4	130	10	10	No	Yes	10
2	30048829	SELL	BID	1	130	10	10	No	Yes	10
2	30048829	BUY	BID	5	130	10	13	Yes	No	10

Figure 5.2: TRADEWISE TRACKER

The Desired Ticks are the ticks which user is expecting to execute its trade at. This is the spread we look into the system and try to grab the best possible scenarios.

Now you can see that we took 9 – 17 ticks in a short span of time resulting in overall profit. Loss happens when someone else grabs the opportunity before we

could and we get the other order. But due to our some checks, we reduce these scenarios to the less possible case.

5.2. Advantages over legacy algorithms

- **Future – Future –** Future-Future does not allowed you cross exchange arbitraging.

  It also doesn't allow you to trade between Futures with same expiry date. You can only buy or sell the order instrument at the same time. In Future-Future, you have to cancel the first order while doing hedging whereas in Cross-Exchange, you can do all the above things and as well, you can run it in the same exchange, same like Future-Future with execution of trades comes out to be 35-40% more than Future-Future due to continuous trading. The only difference in future-future is that it has some defined hedging methods whereas we are doing simple hedging in Cross-Exchange. There is a plan to extend those hedge methods into in the future.

- **TwoLeg-ThreeLeg –** TwoLeg-ThreeLeg cannot also do cross exchange arbitraging unlike cross-Exchange Arbitrage algorithm. Unlike Cross-Exchange Algorithm, it cannot work where there is no depth. It doesn't provide enough parameters to do market making on its own.

  Unlike above strategies, cross-exchange has the support for trading with MSCI Index. It also has support for currency segment whereas for the above, different strategy has to be carved out with four precisions in their price parameter. For IOC strategies, both the above strategies use different parameter, since IOC is about picking opportunity. You cannot afford latency and different behavior is required whereas Cross-Exchange strategy manages itself for IOC order. Its performance for IOC is same as above behaves but the other one are specially customized for this one.

  The advantage this strategy provides is that you can select Cash Segment as well for arbitraging. You can use all the parameters accordingly for the cash segment. You can use it as Cash-Future, Cash-Cash which are different

strategies, whereas other strategies do not provide support for other segments. This strategy has incorporated most of the things of other strategies without affecting its performance.

Chapter -6 Conclusion And Future Scope

Conclusion

In this research, I have created an algorithm which can be used to trade between different exchanges with much sophistication and discipline to get more profit in a consistent way. This algorithm also serves other purpose which is being done by many other strategies already running on muTrade platform. There were number of strategies but no one could do cross exchange trading in low latency which could give an upper hand to the trader. On analysis of the algorithm, we came across that one order from the starting of event till all calculation takes 200 microseconds with prints and timestamp enabled and around 135 microseconds without it on an average server. On live server, latency comes to around 30-50 microseconds for most of the cases depending upon the ongoing scenarios.

This algorithm is currently being used by two financial companies who use muTrade platform product for algorithmic trading. One is using it for trading between NSE Nifty and SGX Nifty, USD-INR currency Future securities over NSECDS, BSEETI and SGXCUR. While other use it for trading between NSE Nifty and MSCI Index and SGX Nifty and MSCI Index.

Future Scope

- More Hedging Method can be included for the reference Leg whereas currently one is being used to hedge off the positions.
- Hedging Methods can also be included for order Instrument in case we do not have given threshold quantity in reference Instrument to square-off the positions.
- To consolidate the call back events of DGCX exchange into the uniform call backs to use this strategy for DGCX.

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Publications

Jasmeet Singh Puri, Dr. Parteek Bhatia and Vinay Arora, "*Cross Exchange Arbitrage Algorithm on High Frequency Trading Platform*", Communicated to ICSCTI2015.

Acceptance Date – 10th August, 2015.

Video Presentation

Video link: https://www.youtube.com/watch?v=2snlzSXZdAU&feature=youtu.be

Reflective Diary

January, 2015

I joined UTrade Solutions Pvt. Ltd. which is the financial technology companies providing different financial technologies software to various companies across many countries. I was selected into muTrade department of UTrade which is into HFT platform related products.

I studied about various financial related terms which helped me understand more relatively about the product. For the first week, we had quite many sessions related to all products and C++ (STL and Boost Libraries) etc.

I was given one strategy to make for one client after one week on its API platform. In API Platform, they provide set of header files to help algorithm get compiled and can be run on its HFT platform. For one full month, I created a design and flow of algorithm and code for the strategy accordingly. It was sent to QA and then process for making it live was done.

February, 2015

I was then given serious task for a bigger client to make customized algorithms for their use. I was given more responsibility of whole API product. I took many demos for different clients in different parts of country out of which many are very big financial companies. I also get into bug fixing of API product while making strategies for them. API can also be provided to the client in whom they can code from their developer but need to compile with our header files included so that our HFT can run their algorithm on its platform.

March, 2015

I started working on Cross Exchange Arbitrage algorithm which is my current thesis topic. I first developed a low level algorithm which client made live but was not satisfied with it.

The main reason behind it was that I was getting successful in implementing everything but sometimes when market gets major movements, strategy started giving loss to the client.

April,2015

Now I was comfortable on this platform after spending 3 months. I was given 3-4 strategies this month with around 2 month deadline for all besides improving this existing algorithm. So major task was to handle all these algorithms and handling all the clients query on API platform.

Work Pressure was there but startup is famous for this and learning opportunity is intense.

I studied other existing algorithms and pick what I can and tried to apply to my research topic, and made a better algorithm. I used Hedging, Threshold, Hop Profit and much more thngs to the algorithms which helped it work in a better way and modified version was made live at client this month after proper QA.

May, 2015

This month mainly gone into making other 2 strategies live at client's server of which I made algorithms and code it. Now 4-5 strategies were live this, month. We used to get some big in some of these for one or other reason. In cross Exchange Arbitrage, we also faced some unheard scenarios which we didn't think. So most of time got into debugging and fixing the bug for it.

Other strategies which went live were Cash Arbitrage, related strategy in which Arbitraging is done on Cash segment. Custom Algo strategy, this is more of a

market making kind of strategy working more with increasing liquidity for financial instruments.

June, 2015

Most of the things got stabled in API strategies till now and new interns joined UTrade this month. So I was given more responsibility of handling existing strategies and more infrastructure building. API strategies are still handled by me but some of its task was given to new Interns who I need to mentor to. New Task took some time before I could grasp my hands on. Company bag one big project for which we need to build new infrastructure from scratch for it. Besides existing algorithms need to be improved with new requirements of bigger clients. So I redesigned existing algorithms to work better with lower latency and better optimization levels. Besides this, I need to handle most of the clients queries for API and demo to the new clients for this specific products independently while earlier, one senior used to sit with me.

Few Things which I have learned here are:

- Efficient Coding in C++ using STL, Boost and proper designing of code
- More hands on use of Linux
- Handle clients with more responsibility and maturity
- Feeling of ownership of product to make it better.

Overall, the experience is excellent and my job is confirmed by them with excellent remarks on training.