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Quality and governance in high frequency trading systems

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May 22, 2013

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Abstract

In the stride for extreme performance in the financial world new challenges and trading strategies has emerged over the last few years. The technological arms race between trading venues and market participant rages on and regulatory entities face the enormous task of regulating the ever changing scene of modern trading. One of the technological advancements the last few years is called high frequency trading. This has been made possible and take advantage of the ultra-low latency communication provided by trading facilities. High frequency trading is one of the most debated subject in financial communities all around the world, and will remain a hot topic the next few years. In this thesis a broad approach is taken to identify some of the challenges introduced by high frequency trading, both technological and ethical. The existing research on high frequency trading is diverse and divergent, but high frequency trading remain unregulated. In this thesis an analysis is provided on upcoming and suggested regulations and a brief summary about the work of regulators. In addition a variety of ethical aspects are addressed and debated. Three proposals are provided, each proposal aims to improve one or more aspects of high frequency trading, and improve overall market quality.

Acknowledgements

There are many people who have contributed in the process of writing this thesis. I would like to express my gratitude to all of them, their support has been much appreciated.

First and foremost i would like to thank my family for encouragement and contributions. Their support kept me motivated throughout the writing period and contributed on many different levels.

My supervisor Tore Hoie has been a great contributor during the entire process. Excellent suggestions, patience and guidance has been outstanding and extremely important.

A big thanks to Stale Vilming and Malin Norberg from Norges Bank Investment Management for insights and guidance.

I would also like to thank Oslo Bors for their contribution. Thomas Borchgrevink and Eirik Finvold has been of great help and contributed to my work with suggestions, valuable insight and their experiences.

Thanks to Peder Veiby for providing his perspectives and opinions.

And finally my gratitude to Harek Haugerud for his efforts as program coordinator throughout the Master's program.

Contents

Chapter 1

Introduction

1.1 Motivation

The global economy of today is a fragile ecosystem strongly dependent on technology, feelings, rumors and liquidity. Trading venues around the world are highly interconnected and together they form a complex web of systems that might be best described using Chaos Theory. Systems theory defines a system to be more than the sum of its parts, and that a system changes when included as a part of a larger system [1]. Chaos emerge when complexity grows and the holistic view of a system becomes too hard to describe and define. The Butterfly Effect is a relevant a term because of the sheer complexity and the sensitive relation between national and global economy. Throughout the history there has been many occurrences that confirm this close relation, a small events can lead to large implications. Unfortunately, technology does not necessarily contribute to less complexity but contribute to quite the opposite. Considering the hunger for new technology in financial venues this complexity is not likely to decrease any time soon. Financial institutions are not to be considered as conservative in their adaption of new technology, and the stride for better and faster systems forces market participants to adapt to the ever changing landscape of modern trading.

In the recent decade there has been a rapid growth in automated trading system such as high frequency trading (HFT), high frequency trading accounts for between 40% and 60% in the US [2]. These software traders have had a strong impact on trading venues, and the debate whether it is positive or negative is ongoing. HFT have also caused incidents on several occasions, the most severe in 2010, known as the Flash Crash. In the wake of these events the debate of security and responsibility regarding automated trading has emerged. Today there are no rules regulating HFTs and how they operate, there are however work in progress to develop an international standard for how HFTs should operate in the global market. This thesis is supplementary to the standard under development, and focuses on two core issues in high frequency trading systems, namely quality and governance. The aspect of quality primarily focuses on the quality assurance in the HFS program code, and market quality, but also relates to security issues when allow a program to operate on

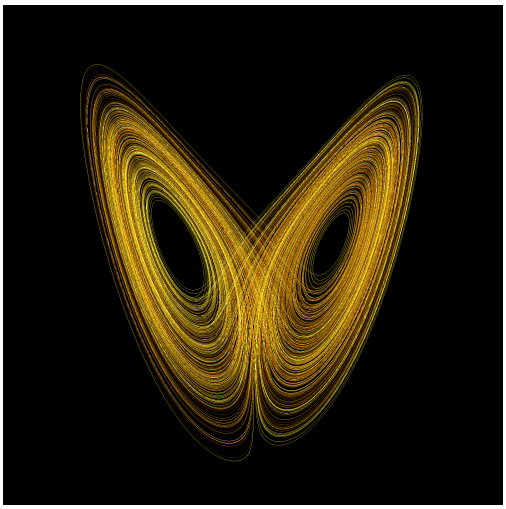

Figure 1.1: Edward Lorenz - Butterfly effect.

a stock exchange. Governance relates more to responsibility and the ethical issues when operating with advanced automated trading systems.

Many financial institutions take advantage of the benefits from a trading operation performed by software code which operates much faster than a human trader would. An HFT can perform a huge number of calculations and operations based on predefined parameters and algorithms in a fraction of a second, giving an opportunity to exploit market fluctuations which human could not do. In principle anyone could write the code for an HFT, it performs in essence two basic operations: buy and sell. It does however require a complex set of algorithms and parameters to operate effectively and profitable, but the fact remains; anyone could program an HFT. Most program code for HFTs are proprietary and written by specialists within a financial institution, and remains as a well kept secret within the organization. There are also attempts to make open source implementations of high frequency trading software, but it seems hard to compete with programs developed by large institutions.

1.2 Problem Statement

The goal of this thesis is to illuminate some of the core issues of modern trading related to technology. Also to highlight aspects discussed in AT9000. At the time of writing there are no rules or laws specifically regulating high frequency trading, this allows high frequency traders to operate in grey area where market imperfections can be abused. This rises the question: What boundaries should an HFT be able to operate within and which kind of exploitations would be considered as ethical? In addition: Who are responsible for the security risks introduced by high frequency trading? The world of trading has become entirely electronic and automatic, this sets the bar for quality extremely high when considering the wast amount of money circulating in the

financial market. The introduction of fully automated trading strategies also bring a question: What quality assurance exist for HFTs and who does the quality assurance?

Chapter 2

Background

2.1 Technological history

Going back 30 years to the 1980s, computers was already being used in trading venues, but only as an informational instrument for traders. Before that the most important technology for information and communication was telephones, pen and paper. The first electronic market was formed when the National Association of Securities Dealer (NASD) began with its automated quotation system (AQ) in 1971 [3]. Today NASDAQ is the worlds seconds largest stock exchange listing a wide range of primarily technological companies [1]. Michael Bloomberg was one of the pioneers in the field of making completely digital infrastructures for stock exchanges and trading venues [4]. In the early 80s he started his own IT company, providing information terminals to all the major participant in the financial markets. By mid-eighties computers were interacting with the market, and was programmed to sell or buy based on certain basic parameters (price). Inevitably this caused a major incident, the event of October 19th 1987 known as Black Monday [5]. Computers might not be solely responsible for this event, but contributed strongly to the cascading events of negative results on all major stock exchanges following the crash in Hong Kong. This event was truly a wake up call for market participants, and remains in the history books as a warning sign for all computer aided trading.

The confidence in computer based trading after this event was not good, and suffered yet another setback by a hedge fund named Long Term Capital Management (LTCM) almost a decade later [6]. LTCM caused enormous losses for investor, which consisted of high ranking Wall Street firms. This hedge fund relied on advanced algorithms for arbitrage trading performed by computers, and in the beginning they were highly successful and profitable. As time went others started to imitate and adopt their trading strategy, which lead LTCM to search for new opportunities in new markets and other methodologies to remain profitable. This meant taking increasingly larger risks and in 1998 they were on the brink of bankruptcy because of failed strategies. LTCM was however saved by the Federal Reserve to prevent a sharp price decline as

[1] http://www.forbes.com/pictures/eddk45iglh/tokyo-stock-exchange/

seen in October 1987. In the following years, along side with the introduction of the World Wide Web, other technological success stories, and diminishing hardware cost, automated trading got a new beginning. With the introduction of internet and declining prices for computer hardware, new opportunities opened up for trading. New web-based marketplaces began to emerge, and new trading firms made online trading available to consumers.

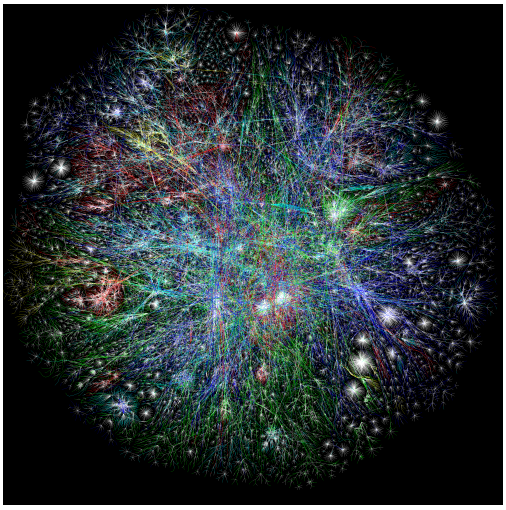

Figure 2.1: Illustration figure of interconnectivity of the internet.

The development in trading venues has continued to evolve through out the last decade, and has been characterized as "Rise of the robots" [4]. Market participants started to develop automated execution systems (AES) and as they improved and became trusted, the focus for optimizing trading efficiency shifted towards algorithms. AES was designed to minimize market impact when executing large transactions, but also to free up time for human traders. With other technological inventions like Straight-Through Processing (STP), (DMA) and Smart Order Routing (SOR), trading venues are now fully automated and digital. These innovations combined with the stride for ultra-high speed and ultra-low latency communication channels has provided the platform for a new type of trading, high frequency trading. High frequency trading has emerged the last few years, and is today a substantial part of most trading venues. Other factors that have played a vital role in the evolution of AT and HFT is new market access models and fee structures.

Computer technology has been the driving factor in trading venues since its introduction, and financial institutions is not to be considered as conservative in their adoption of new technology. As new technology evolves, so does the markets around the world, new software and hardware devices are constantly enhanced and trading venues move to new and more sophisticated platforms. This brings new capabilities and improvements in many areas such as speed which is the primary focus of this thesis. Technological improvements has many advantages, but it also comes with a dark side. As new technologies has been implemented and trading venues has evolved, so has the

level of complexity. This is one of the main challenges market participant face in the United States today, and is subject to wide financial and political debate. Since Regulation National Market System (Reg NMS) was introduced in 2005 the sheer number of trading venues in USA has gone up to over 50, which by itself leads to a level of complexity not to be underestimated. The debate concerning computerized trading is ongoing and has been a focus point since the "Flash Crash" of 2010, and is discussed in political venues as well as regulatory functions like the Security and Exchange Commission (SEC) and Commodity Future Trading Commission in the US. We observe the same discussion in other parts of the world as well. The European Commission consisting of 27 member states of the European Union, plus Norway, Iceland and Liechtenstein, are working on a new revision of "Markets in Financial Instruments Directive" (MiFID) where high frequency trading is on the agenda.

2.2 Technological arms race

The consequence of the financial institutions dependence on computer technology and software is that IT departments continue to grow and plays an even more vital role than ever before. Besides expansion of IT departments all companies that rely on advanced algorithms also hire mathematicians and statistics experts to optimize trading strategies and algorithms. The trader profession has not disappeared but they now have to work closely with the mathematicians and IT consultants. At the time of writing one of the most profiled high frequency trading companies, Global Electronic Trading Company LLC (GETCO), has a long list of IT related job openings. By looking at this list, 2.2, it is not hard to determine their business strategy. Included in the list are several programmer jobs, FPGA developers and network administrators, which together form the technical foundation for high frequency trading.

GETCO is by no means alone in the world of high frequency trading, but they have been in the spotlight ever since the Knight Capital incident. Knight Capital is also one of the leading technological and automated traders, and when the merger with GETCO is completed it will be technological fortress. Many of the large firms from the US are also present in the European market, and that also included HFT firms like GETCO. In Europe the HFT firms seems to center around birth place of the stock exchange, in Amsterdam we find the headquarters of three of the largest HFT firms in Europe: IMC, Flow Traders and Optiver [7]. The arms race does not only apply to competing market makers, broker-dealer and other trading firms. To fully utilize highly capable and extremely fast trading systems there need to be someone in the other end that has the capacity to communicate at the same speed. Trading venues also competes for business, and falling behind in technological advancements will put them at a disadvantage.

[2]http://ch.tbe.taleo.net/CH04/ats/careers/searchResults.jsp?org=GETCOCAREERS&cws=1

Title▲	Location
C++/Java Trading System Developer - Chicago	Chicago
C++/Java Trading System Developer - London	London
FI Developer - Chicago / New York	Chicago
FI Developer - New York	New York
FI Quant - New York	New York
FPGA Developer - Chicago	Chicago
FPGA Developer - Chicago	Chicago
Front Office Developer - Chicago	Chicago
Front Office Developer - New York	New York
GES Production Support Engineer - New York	New York
Head of Commodities Trading - Chicago	Chicago
Networking Administrator - New York	New York
Operations - Singapore	Singapore
Ops Developer (EQ Support) - Chicago	Chicago
Q Systems Level Developer - Chicago	Chicago
Quant - Chicago	Chicago
Quantitative Trader - London	London
Simulation Developer - Chicago	Chicago
Systems Architect - Chicago	Chicago
Systems Architect - New York	New York
Trader - Singapore	Singapore

Figure 2.2: GETCO job openings as of March 19, 2013 [2]

2.2.1 Connectivity and Latency

Since the introduction of Reg NMS and MiFID all market participants in the US and EEA have had to invest in high performance connectivity solutions to be fully compliant with new policies and regulations. Orders needs to be displayed in a fair fashion on all trading venues, in other words be displayed at the same time, giving investors the same opportunities regardless of geographical location. This requires high speed links with very low latency and this can be challenging if the geographical distance is long enough. This is one of the reasons why trading venues are centralized around already established financial districts like New York and London, but also why market participants move to the geographical location of a trading venue. To be competitive in the markets many trading venues offer different types of connectivity solutions and proximity hosting (colocation services). Communication links are generally offered as a direct link and offered at a variety of speeds ranging from 1 megabit up to two digit gigabit speeds.

Figure 2.3: Example of a fiber optic cable

There are two protocols primarily used in financial markets: Society for Worldwide Interbank Financial Telecommunication (SWIFT) and Financial Information eXchange (FIX) [4]. Both these protocols handle trade-related messages providing a common interface and communication for electronic trading. SWIFT was conceived in 1973 and were in the beginning supported by 239 bank in 15 countries, today SWIFT has over 200 member countries and over 10 000 member institutions and corporations. In January 2013 SWIFT handled over 400 million messages with an average daily traffic of almost 20 million messages [3]. The FIX protocol is recognized by many market participants as the industry de facto standard, and is used by a long list of investment banks, broker-dealers and exchanges. Among them are large exchanges like NASDAQ, Chicago Mercantile Exchange (CME), Deutsche Boerse and Oslo Bors [4]. Fix Protocol Limited (FPL) maintains the FIX protocol, this organization consists member firms from the entire trading value chain [5]. The work of the member firms is voluntary and are organized by a Global Steering Committee.

Trading venues use standardized protocols for communication but also provide another option for communication. Standardized protocols are very flexible and versatile, but suffer from speed limitations related to packet processing. Each FIX/SWIFT-packet requires encapsulation and includes extensive header information which is not always required. To overcome speed and latency requirements most trading system also provides a binary option. This type of communication is much faster because no excess information is sent, a bare minimum of information is included in this type of communication. A binary stream with a fixed format is used, making packet processing a lot faster. This is required in the modern high speed market, and contributes to the enabling of high frequency trading.

The industry standard for connectivity is fiber optical network links, although other options are available, fiber optic is the preferred choice for anyone relying on low-latency. Network capacity is not the primary goal of these network links, it is generally focused on latency. As an example, SFTI offers 5Gb links to various locations in New York where the SLAd latency figures are measures in microseconds [6]. In the stride for ultra-low-latency network links there has been experiments with even faster network links built on microwave technologies. The advantages of using microwaves is that the signal travels in a straight line, which can lower latency even further than with fiber optics. When installing a physical cable all obstacles on the way will add distance and therefor increase latency. Fixnetix is one of the companies offering this type of connectivity, and has successfully installed a microwave link between London and Frankfurt [7]. According to their own press release the signal travels 35%

[3] http://www.swift.com/about_swift/company_information/swift_history

[4] http://www.fixprotocol.org/members/

[5] http://www.fixprotocol.org/what-is-fix.shtml

[6] http://www.nyxdata.com/doc/83354

[7] http://www.fixnetix.com/news/fixnetix-offers-microwave-access-between-london-and-frankfurt/

faster than an average fiber optic network link [8].

The complex network that is the modern trading face exactly the challenges that network administrators face in other types of non-trading related networks. When designing advanced algorithms one of the factors one need to consider and accommodate is network delay or more accurately packet delay variation (PDV). There are several factors that contribute to PDV:

Signal propagation delay is the delay introduced when transporting at signal from A to B. Although modern network links use fiber optic cables, with light as the transmission medium, the sheer distance between two locations might so large that even the speed of light introduce a delay. The distance between London and New York is about 5500 km, which in terms of latency correspond to about 18 ms at light speed.

Serialization Delay is the delay introduced when converting data from signals to values stored in a memory buffer, the delay equals packet size divided by the bandwidth.

Minimum Idle Period is the idle time between transmission of frames in Ethernet. This time gap allows devices to prepare for the next transmission and is known as Inter-Frame Gap.

Routing and Switching Delay is the time a router or switch use to forward a packet from an input interface and forward the packet through an egress interface. This occurs on every node along the way during a transmission, but is not a large contributor to delay in modern network. Other types of delay accounts for much larger percentage of the total packet delay.

Network Processing Delay is introduced by the same network devices as the previous, but is a results of packet processing. This included MTU fragmentation, encapsulation, NAT and other operations performed based of the type of device.

Queuing Delay is related to congestion on a network device. This occurs when multiple packets are destined to depart from the same egress interface the device need to build a queue and send the packets sequentially. This type of delay can be a substantial amount of the total delay registered on a single packet compared to the other types of delay.

Together all the above contributes to the total PDV and this is one of the challenges faces when operating a high speed low latency trading strategy. Low latency is one of the benefits by using proximity hosting where the number of network nodes between a "trader" and the trading system is reduced to a minimum. Direct network links are also used to provide market participant, this type of link might be just as efficient with the right type of infrastructure

[8] http://www.fixnetix.com/news/fixnetix-turns-on-the-microwave/

and geographic proximity to a trading venue. DMA and SA are two types of network links connecting a trader to a trading venues order book, see the definition section for description of DMA and SA.

2.2.2 HFT code

It is not hard to understand why software code for HFTs are well-kept secrets within an organization, and probably also within the organization it self. There has been cases in the US where company employees have been legally pursued after leaving the company with proprietary code for trading algorithms. A former employee at Goldman Sachs stole the firms source code for their HFT system when leaving the company to start his own firm. This is not unique for the financial community, companies developing software have strict regulations to protect company property and intellectuals. The Open Source community has over the years also been developing trading system, but only a few focus on algorithmic and high speed trading. One of these is called Marketcetera, this project received quite a bit of news coverage and promise when it was launched in 2008.

"Marketcetera democratizes access to high frequency trading. Our Open Source Automated Trading Platform provides you with the agility to implement your new strategies in moments, even while you reduce your infrastructure costs." [9]

This project does not seem to be alive at the time of writing, and it is not apparent why they are offline. The last signs of life was July 23 2012 when version 2.2 was released, and at the time they had a large active community. The idea of Marketcetera was very appealing as they provided low cost entry to the world of of high speed trading and it appeared that many companies were exploring this opportunity.

Two of the world's most used programming languages, C and Java, is also two of the top candidates for high frequency trading applications [10]. There are however limitations within Java that makes it less suitable, java lacks control over caches, context switches and interrupts. For ultra fast low-latency systems, like FPGA, other low-level programming languages are used. For this kind of use, C and assembly are probably more appropriate (and faster) . Building a high speed trading platform can probably be done in any modern programming language. There are even specialized libraries to solve eventual shortcomings in the native language, there is for example a library for Java called "javolution" which offers high speed enhancements. Even though speed is very important when choosing a programming language for a trading system, there are also other aspects to consider. Each trading system need to communicate with a variety of other types of systems, not only the feed to and from an exchange. Important key word are: flexibility, interoperability and flexibility.

[9] http://www.marketcetera.org/

[10] http://vanillajava.blogspot.no/2011/07/c-or-java-which-is-faster-for-high.html

2.2.3 Standards

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) have over the years developed many standards. These are guiding principles for various industries, and for companies providing IT related services these standards are widely acknowledged and adopted. Standards related to many aspects of ICT, some of the most important topics relative to high frequency trading are: quality, governance/management and compliance. All of these topics are thoroughly described in different ISO standards, all related to ICT.

Governance defines an organization's structure, management and how it operates, governance covers administrative aspect as well as routines and ethical aspects. Important aspects of governance is identification of roles, decision processes and identification of key stakeholder. Ethics is a large part of governance, both for internal member of an organization and the perception of the organization from an outside party. The latter often relates to social responsibilities, and in the domain of this thesis, economical responsibilities. From the inside, members of an organization will relate ethical aspects to decision making processes, transparency and other social aspects that affect the working environment. Governance must be distinguished based on the type of organization, meaning that the governance framework of a financial institution will not be identical to a medical institution. Financial institutions are bound by regulations and policies set by authorities and regulatory entities, these affect the governance structure in the sense that they must be compliant to operate in the financial market. In corporate governance there is usually a board of directors that is positioned above the management group that handle day-to-day operations. The board of directors is an essential part of the decision making process, and to establish corporate strategical goals and visions for a company.

Figure 2.4: UNESCO - Good Governance [11]

Identification of governance and good governance is often easiest to identify by the lack of it. UNESCO has defined 8 characteristics of good governance as seen in 2.4. These characteristics are appropriate for any type of organization, and some characteristics might be conflicting with the general perception of financial organizations. The financial world might however be wrongly

[11] http://www.unescap.org/pdd/prs/ProjectActivities/Ongoing/gg/governance.asp

perceived, many of the largest investment banks and other market participant have a clear outspoken ethical profile and follow good governance. All of the characteristics represents important aspects for a sound organization with integrity, good governance is important for the successfulness of an organization.

Credit Suisses corporate governance complies with internationally accepted standards. We recognize the importance of good corporate governance and know that transparent disclosure of our governance helps stakeholders to assess the quality of the Group and our management and assists investors in their investment decisions. [12]

Credit Suisse has clearly acknowledged the importance of good governance, and has extensive information about their business on their web page. There are several other good examples of outspoken governance profiles, but unfortunately there are also many examples of the opposite.

Quality is a key element in all types of service providers or manufacturers, good quality forms the basis for successful operation. Good quality is perhaps easier to relate to things you can see and touch, but it is equally important when writing lines of code for a software program. Bad quality software applications might not be easy to identify until it inevitably has a serious error and crashes. For financial applications this usually means loss of money, of the more extreme examples, software errors in airplanes might have lethal consequences. To ensure good quality software companies need a good quality management system (QMS). QMS defines corporate structure, procedures, processes and resource management among others, and for the baseline for quality assurance and good quality products. The ISO 9000 series can be used to established QMS, and is widely implemented throughout the world. ISO 9000 has 8 key principles:

- Customer focus
- Leadership
- Involvement of people
- Process approach
- System approach to management
- Continual development
- Factual approach to decision making
- Mutually beneficial supplier relationships

[12] https://www.credit-suisse.com

Collectively these principles forms the framework for performance improvement and organizational excellence needed to provide high quality services and products. The motivation for implementing ISO 9000 might be financial performance and profitability. But the benefits of being ISO 9000 certified extends to far more aspects than increased revenues, and in a long-term perspective the investment of becoming certified is likely to pay off.

Another ISO standard relevant for financial institutions is the ISO 20000 series, the standard defines requirements for service management system. ISO 20000 is perhaps not primarily intended for financial institutions, the standard is closely aligned with ITIL. It is however highly appropriate for trading firms, market makers and others that deliver market access as a service to others. Market making firms deliver very similar service as an outsourcing partner would as an external IT department. There are several other standards that could be incorporated in the financial community, for instance ISO 38500 for corporate governance and ISO 27001 for information security management systems. In essence the financial world has become so dependent on technology that many ISO standards could, and perhaps should, be incorporated.

2.3 Computer based trading

The term Computer based trading (CBT) can be slightly misleading and could just as well be name Computer aided trading. CBT does not necessarily entail automation. CBT is used in this thesis as a generic term for all types of trading performed by a computer and covers both algorithmic trading and high frequency trading as discussed below.

2.3.1 Algorithmic trading

Algorithmic trading (AT) is defined by CFCT as The use of computer programs for entering trading orders with the computer algorithm initiating orders or placing bids and offers. Meaning that AT is not fully automated without human intervention, but require input by an operator or trader. Algorithms are used on both the sell-side and the buy side, with same objective for both, optimizing a trade to maximize profit. Algorithms are used in both pre-trade analysis and order execution. Before entering an order algorithms are used to analyze real-time and historical data for a particular share, and also perform a market analysis and in some cases analyze non-market data. The algorithm helps the trader to make an informed decision. When the decision has been made, either buy or sell, and algorithm can assist in minimizing the market impact of an order. Meaning that if there is a large order, an algorithm can buy or sell smaller parts of that order over a period of time to ensure that the share price is not considerably influenced.

2.3.2 High Frequency trading

HFT is a relatively new term, but even though it has existed for quite some time there is no well established definition. The "European Securities and Markets Authority" (ESMA) defines HFT as:

Trading activities that employ sophisticated, algorithmic technologies to interpret signals from the market and, in response, implement trading strategies that generally involve the high frequency generation of orders and a low latency transmission of these orders to the market. Related trading strategies mostly consist of either quasi market making or arbitraging within very short time horizons. They usually involve the execution of trades on own account (rather than for a client) and positions usually being closed out at the end of the day. [8]

The "U.S. Commodity Futures Trading Commission" (CFTC) defines HFT as:

High frequency trading is a form of automated trading that employs: (a) algorithms for decision making, order initiation, generation, routing, or execution, for each individual transaction without human direction; (b) low-latency technology that is designed to minimize response times, including proximity and co-location services; high speed connections to markets for order entry; and (d) high message rates (orders, quotes or cancellations). [9]

Both of these definition are proposals and working definitions, this means that they might be changed in the future. ESMA has however released guidelines on high frequency trading based on this definition, and changing the definition will also affect the scope of their guidelines. It is noteworthy that the definition from CTFC lacks one of the key aspects of HFTs related to liquidity. High frequency trading normally implies that it will be closed out at the end of the day. HFTs tries to keep its inventory to a minimum, meaning that it will start and end a trading day with the same inventory size. HFTs try to be profitable based trading volume rather than a long-term position. The aspect of holding times or long-term/short-term positions is intentionally left out from the CFTC definition. The CFTC is carefully avoiding characteristics that may label high frequency trading as good or bad. Both two definitions agree on two important aspects, the speed and the use of algorithms. High frequency trading is a subgroup of algorithmic trading, so the usage of algorithms is implied and the speed is self explanatory by its name.

Definitions of high frequency trading varies among reports and in regulatory entities, high frequency trading can be referred to as a trading strategy or as a trading technique. High frequency trading is referred to as a trading technique in this thesis. HFT is generally speaking a computer program capable of making it own decisions based on mathematical and statistical data, but with the extreme requirements for low latency trading the HFTs needs to operate at a faster pace than a regular server is capable of. To improve the speed of there has been developments towards specialized hardware devices such as

field-programmable gate arrays (FPGA). FPGA are silicone chips with large arrays, logic gates and interconnection wires that can be programmed. These devices operate at wire-speed and is able to make buy or sell decisions much faster than a normal computer. There are multiple companies specializing in development of these devices providing HFT firms with forefront technology.

Research reports and studies have different opinions about positive and negative sides of high frequency trading [10]. The positive side most commonly referred to is narrowed "bid-offer spread" [11, 12, 13]. Negatives side are more widely acknowledged, but the implications are more disputed. Market quality and integrity is severely affected by the negative aspects and some characteristics are illegal by market manipulation laws. The three most common characteristics are: Layering, quote stuffing, and momentum ignition.

Layering is a strategy to manipulate market prices by creating a false perception of market sell pressure. Multiple sell-orders are entered to create an impression of a strong sell-pressure, and then buy-orders are entered at a desirable price. When buy-orders executes the sell-orders are cancelled, and the trader benefits from buy-orders executed at a falsely created low price [14]. Trillium Brokerage Services LLC has been fined by FINRA for this kind of market manipulation [13].

Quote stuffing is a strategy to flood the market with large amounts of orders in a very short timeframe and then either cancel or change the orders. This strategy is comparable to "Denial-of-Service" attacks, where the intention is to overload other market participants with excessive information [14].

Momentum ignition refers to a strategy of triggering other market participants to trade because of rapid price movement. This strategy can be beneficial by taking a pre-position and selling off securities when the price incline, or by buying order after a price decline [14].

2.4 Regulations

2.4.1 Regulation Alternative Trading Systems

Market structure in the US has been formed by the Securities Exchange Act of 1934, and the amendments from 1975 to establish a "National Market System" (NMS). Regulation National Market System (Reg NMS) was created by the SEC and implemented in the US in 2007. "The NMS is premised on promoting fair competition among individual markets, while at the same time assuring that all of these markets are linked together, through facilities and rules, in a unified system that promotes interaction among the orders of buyers and sellers in a particular NMS stock" [15]. The aims of Reg NMS is to

[13] http://www.bloomberg.com/news/2010-09-13/trillium-brokerage-fined-1-million-by-finra-over-illegal-trading-strategy.html

interconnect markets and establish a unified national market system. Also to enhance competition among trading venues. New communication technology and data processing advancements allow markets to be further interconnected and more efficient. Reg NMS consists of four primary rules:

Order Protection Rule This rule promotes the founding principle of fairness in trading, giving investor price assurance and protection against ”trade through”. This implies that all markets must communicate with each other, and maintain a fair system for order routing.

Access Rule The ”Access Rule” is closely related to the previous rule and provides market participant with a fair and efficient access to the markets or National Market System. This is done by using private high speed links instead of ITS. The access rule also sets a limit on access fees charged for execution orders at a particular market.

Sub-Penny Rule To address the issue of ”stepping ahead” this rule was included in Reg NMS. The rule prevents all markets from displaying, ranking or accepting quotes that are priced in increments of less than a penny. The rule does not apply to stocks priced at $1 or less. This effectively stops a buyer from increasing his quote by an economical insignificant amount to step ahead of another buyer.

Market Data Rules and Plans This rules is in essence an updated formula for allocating revenues for SROs. Instead of calculating revenues based on volume it calculates revenues based on the value of quotes and trades. This effectively prevents what is known as ”wash sale” and ”shredding”, where the only objective is generate volume.

These four rules is the basis of todays markets in the US, where all markets can be viewed as a holistic and uniform unit. As Reg NMS promotes and requires technological inventions it can be perceived as the starting point for the technological evolution of the US market.

2.4.2 Markets in Financial Instruments Directive

Markets in Financial Instruments Directive (MiFID) was issued in 2004, and effectuated November 1 2007. MiFID was developed by the European Union, with its respective member, along with Norway, Iceland and Liechtenstein. The latter three are not members of the European Union but are members of the European Economic Area (EEA). MiFID has many of the same objectives as Reg NMS, promoting fairness among individual market participant. The term best execution, in financial lingo, is closely related to fairness, best execution provides investors with the best overall execution of a trade. Best execution is however not uniquely related to price, trading costs at an execution venue will also affect where the order is executed. The term Best Execution is the mantra of MiFID: Member States shall require that investment firms take all reasonable steps to obtain, when executing orders, the best possible result for

their clients taking into account price, costs, speed, likelihood of execution and settlement, size, nature or any other consideration relevant to the execution of the order. Nevertheless, whenever there is a specific instruction from the client the investment firm shall execute the order following the specific instruction. With the implementation of MiFID all affected European trading venues could now be viewed in a more holistic view, much like the US markets post Reg NMS.

2.4.3 ESMA Guidelines and MiFID 2

Even though MiFID was implemented only 6 years ago, ESMA saw the need to further regulate market, and on February 24 2012 they released a report with eight suggested guidelines for automated trading. These guidelines came as a direct effect of the rapid growth in algorithmic and high frequency trading, and all eight guidelines are related to these two types of trading. The guidelines will in all likelihood be included in revision 2 of MiFID, and forms a basis of the directive concerning the above mentioned trading strategies. Most of the guidelines are related to key questions regarding AT and HFT, namely: governance, security and testing. All these topics are key elements in all discussion regarding AT and HFT. The guidelines target all types of market participants all across the EEA, market makers, trading venues and stock exchanges. The short version of the eight guidelines is as follows: [8]

1. A regulated markets or multilateral trading facilitys electronic trading system (or systems) shall ensure that it complies with applicable obligations under MiFID and other relevant Union and national law taking into account technological advancements and trends in the use of technology by its members/participants or users. ....

2. An investment firms electronic trading system (or systems), including trading algorithms, shall ensure that the firm complies with applicable obligations under MiFID and other relevant Union and national laws as well as the rules of the trading platforms to which it sends orders. ...

3. Regulated markets and multilateral trading facilities rules and procedures for fair and orderly trading on their electronic markets should be appropriate to the nature and scale of trading on those markets, including the types of members, participants and users and their trading strategies.

4. Investment firms must have policies and procedures to ensure that their automated trading activities, including where they are providing DMA or SA, on trading platforms comply with their regulatory requirements under MiFID and other relevant Union and national laws and, in particular, and that they manage the risks relating to those trading activities.

5. Trading platforms should have effective arrangements and procedures, taking account of the specific supervisory arrangements/regulation in

their Member State, which enable them to identify conduct by their members/participants and users that may involve market abuse (in particular market manipulation) in an automated trading environment.

6. Investment firms should have policies and procedures in place to minimize the risk that their automated trading activity gives rise to market abuse (in particular market manipulation).

7. Trading platforms should have rules and procedures which seek to ensure that, where they allow members/participants or users to provide direct market access/sponsored access (DMA/SA), the provision of DMA/SA is compatible with fair and orderly trading. It is important that trading platforms and their members/participants retain control of and closely monitor their systems to minimize any potential disruption caused by these third parties to avoid that trading platforms are vulnerable to either the potential misconduct or market abuse of DMA/SA clients or to their inadequate/erroneous systems.

8. Investment firms offering DMA/SA to clients (DMA/SA clients) are responsible for the trading of those clients. They must establish policies and procedures to ensure the trading of those clients com plies with the rules and procedures of the relevant trading platforms to which the orders of such clients are submitted and enables the investment firm to meet its obligations under MiFID and other relevant Union and national law.

2.4.4 AT9000

AT9000 is a quality management system standard that builds on and extends the ISO 9000 standards series. It is currently under development by ANSI working group ”X9 D14” and the draft used in this thesis is draft number 13 from November 20, 2012. AT9000 is specifically designed for ”automated trading industry organizations” (ATIOs), and sets forth a series of additional/adopted QMS requirements from ISO 9000 [16]. It is designed with respect to recent events and concern for market structure related issues. AT9000 have three aims for the QMS it defines:

1. *Satisfying their responsibility for trading safety.*

2. *Satisfying regulatory requirements.*

3. *Achieving improved efficiency and effectiveness.*

These three aims translate to three, already discussed, key principles: fairness, governance and quality. AT9000 has nine quality management principles, one more than the original ISO 9000 which has eight. The additional principle is called ”Trading safety first”, the remaining principles are very similar to ones defined in ISO 9000, and previously presented. The term safety, relates

to the introduction of and influence of systemic risks when operating with automated trading systems. Organizations involved in automated trading must acknowledge the systemic risk they introduce, and must acknowledge their responsibilities accordingly. The major difference between AT9000 and ISO 9000 is the scope, ISO 9000 is a general standard for all types of organizations. AT9000 is directed at a very narrow scope of organizations within the financial community, when the core focus is automated trading.

2.5 Incidents

Computer technology has been a strong contributor in the evolution of stock exchanges and other markets in the financial world, todays markets are more efficient and capable than ever, but also more complex. Software development for an already complex systems is difficult, and as complexity grows the margin for errors decrease and the number of errors increase. According to Dr. Nancy Leveson the software code for NASAs space shuttle program, contained 27 errors critical errors in 1992 [17]. NASA was at the time using astronomical amounts of money in software development and maintenance, NASA also employs some of the brightest and best IT personnel in the world. Financial organizations face a very different set of challenges than NASA, but they are both strongly dependent on high quality software for a successful operation. Software errors can have fatal outcomes for NASA missions, but although the fatality from software errors in financial organizations is not the same, the results from software bugs can still be catastrophic. A research company called Nanex has documented over 2 000 instances of ”Mini Flash Crashes” over the last couple years [18]. Most of these incidents does not reach the general public, the number of incidents who have reached the general public is fewer in number but a lot larger in scale.

2.5.1 The Flash Crash

During the financial crisis of 2010, markets in the USA experienced the most severe incidents involving HFTs in history, this event is commonly known as the Flash Crash. May 6th started as an unusually turbulent day for markets because of negative trends in Europe and the debt crisis in Greece, which led to a sharp price volatility of some individual securities and the Euro declined against both USD and JPY. By 2:30 pm on this particular day the E-Mini had declined 55 percent from an opening level of almost $6 billion dollars to $2.66 billion dollars. In addition the S&P 500 SPDR exchange traded fund - SPY - had declined 20 percent from $275 million dollar to $220 million dollar. At 2:32 p.m. a large trader initiated a ”sell algorithm” in order to sell 75 000 E-Mini contracts with a total value of approximately $4.1 billion dollar. This algorithm was programmed to execute automatically with a predefined set of parameters, which was an execution rate of 9% of the trading volume calculated over the previous minutes and not considering price or time. Even though the markets was already in a high stress situation the trader chose to execute the ”sell

program" in just 20 minutes. The initial sell orders was rapidly absorbed by HFTs as the most likely buyers and as a result HFTs built up a temporary long term position. The amount of securities absorbed by HFTs conflicts with the fundamentals of an HFT as they, at the end of the day, should have a minimum inventory. The results of this was that HFTs started to aggressively sell E-Mini and SPY contracts to reduce their inventory, causing a huge amount of trades between 2:41 p.m. and 2.44 p.m. In this period of time the HFTs traded about 140 000 E-Mini contracts, 33% of the total trading volume. As a response to the increased trade volume, the sell algorithm fed more orders in to the market at a higher frequency.

These events caused both SPY and E-Mini prices to drop 3 percent in a matter of minutes. The E-mini as a results of the sell algorithm and the SPY as an effect of HFTs buying large amounts E-Mini contracts forcing HFTs to reduce their inventory. This generated a "hot-potato" volume effect as the HFTs was buying and selling from each other as the market lacked a presence of fundamental buyers. During a timeframe of just 14 seconds between 2:45:13 and 2:45:27 HFTs traded over 27 000 contracts, and at this time, this was almost 50 percent of the total trading volume. A "Stop Logic Functionality" was eventually triggered at 2:45:28 p.m. on the Chicago Mercantile Exchange to prevent cascading price declines, but at this point the E-Mini had fallen to about $58 million, less than 1 percent from its morning level of $6 billion. The 5 second pause triggered by "Stop Logic" limited some of the sell-side pressure caused by HFTs and E-Mini stabilized as the buy-side interest increased again. There were however still problems, during the time between 2:40 and 3:00 p.m. about 2 billions shares was traded with a total value of $56 billion, but 98% of these shares was within 10% of the price level at 2:40. Over 22 000 trades was declared clearly erroneous and was cancelled. As the markets had time to respond to the events between 2:40 and 3:00 p.m. and a normal price discovery process was functioning again both the sell-side and buy-side began functioning a normal matter again. Both E-Mini and SPY had recovered to its consensus market value.

2.5.2 Knight Capital

On August 1. 2012 a software error struck one of the largest market makers in the US, Knight Capital Group Inc. In about 45 minutes with software problems Knight lost over $440 million and caused errors in a wide range of shares on NYSE Euronext [14]. Trades made 30% or more away from the starting price of that day was declared erroneous and cancelled by NYSE Euronext, counting only 6 of 140 affected securities. At the time of writing it does not exist any public reports explaining exactly what went wrong that day, but all evidence point to a dormant software mistakenly activated or inserted into the live stock exchange system. This event happened only 5 months after the BATS software glitch on March 23 and the Facebook IPO fiasco on NASDAQ May 18. In De-

[14] http://www.bloomberg.com/news/2012-08-14/knight-software.html

cember 2012 Knight Capital reached an agreement with Getco to merger, both these companies trade with sophisticated computer technology.

2.5.3 BATS

The IPO of BATS Global Markets Inc. on March 23 2012 is yet another example of how programming errors can lead to disastrous events. BATS is one of the largest ATS in the US, accounting for about 11% of the stock trading volume in the US [15]. On March 23 BATS launched their IPO on BZX Exchange with an asking price of $16 per share. At around 10:45 AM BATS reported that they had errors related to the opening to the opening auction, this included ticker symbols from A - BZZZ. At 10:57 AM AAPL stocks were traded on BZX with a 9% decline compared to other trading venues. This caused a trading stop in AAPL stock for 5 minutes in the entire market. At 11:14 BATS shares were changing hands at $15.25 from the opening auction. Within 900 milliseconds of the opening auction, BATS stock prices had fallen from $15.25 to $0.2848, and bottomed out at $0.0002 within 1.5 seconds. The trades executed between 11:14 AM and 11:15 AM was later cancelled and BATS took the unusual step of withdrawing their IPO because of this dramatic drop in share prices. The interesting part of this event is the time aspect and the fact that there does not seem to be any definitive evidence of the cause. With a timeframe of 900 milliseconds is obvious to point to high frequency and algorithmic trading, and there has been speculations on various venues wether the BATS incidents was intentional or just a computer glitch.

2.5.4 Timber Hill

One of the very few, law enforcement driven cases involving HFTs happened in Norway in 2010. Two Norwegian day traders were accused of market manipulation through an HFT operated by Timber Hill (Europe) AG. The counterpart in this trial was however not Timber Hill but The Financial Supervisory Authority of Norway. This cases started when Oslo Bors discovered anomalies in trades between the two day traders and the HFT robot, Oslo Bors proceeded to report this to the police and they were charged with market manipulation. After being convicted in Oslo District Court the two men appealed their case to Borgarting Court of Appeal and were acuited. The case was further appealed to the Supreme Court of Norway, whom in turn withheld the verdict from Borgarting and the two men were acquitted on all charges [19]. The final verdict of the Supreme Court of Norway fell on May 2, 2012, the first verdict from Oslo District Court fell on October 12. 2010. The trades in question pre-dates the final verdict by over four years and took place from December 2007 until March 2008. During the time in the legal system the two day traders received massive support from the financial community in Norway, and many argued that what they did is not illegal.

[15] http://www.bloomberg.com/news/2012-03-23/bats-withdraws-ipo-after-errors-pummel-its-stock-halt-apple.html

One of the reasons why its was possible to exploit the algorithm used by Timber Hill was that it was poorly designed and should not have responded as it did. In an interview one of the defendants has admitted that he could have made a lot more money of the Timber Hill robot and that this was a classic case of badly implemented algorithm trading in the wrong types of stock. There are three interesting points to extract from this case, first of which is the amount of time spent by the police investigating this case. It took over two years from the time when Oslo Bors reported the two traders until they first appeared in court. The case was also brought forth to the supreme court, which indicates that this case was important for the future and the guiding function of the supreme court was needed. The third interesting aspect is the fact that a human can actually outsmart a robot or an algorithm in this case. This shows and confirms two important properties of CBT, algorithms are not perfect and should be monitored, and that human traders are still needed in the market.

Chapter 3

Approach

The following chapter describes the scientific approach of this thesis and a description of interviews and parties that have been interviewed.

3.1 Research

This thesis is based on the concept of exploratory research, which implies that the unknown is explored and there might not be definitive final answers. The goal of this thesis is to shed light on some aspect regarding high frequency trading and one possible outcome are proposals intended for future work and/or open proposals to consider for authorities. Since the nature of trading algorithms and program code for HFTs are proprietary and well kept secrets there will not conducted any form of experiments. Existing empirical research on high frequency trading is scarce and only applicable to a single domain. Meaning that research on high frequency trading on one trading venue is unlikely to be directly transferable to other trading venues. Despite this there is still valuable information and conclusion in the few empirical studies, but these are more applicable in financial studies. Since this thesis is written in a computer science context, this will also be the focus throughout this thesis. There are many ethical aspects related to trading, and high frequency trading is no exception. The ethical aspect of high frequency trading will also be explored in this thesis, and relevant theories and paradigms will be presented. One of the key aspects to all computer dependent system is quality. Another important ethical aspect is stakeholder theory, this is an important theory in ethics for management and governance.

3.1.1 Quality and Quality management

High quality products can only be achieved through a high quality process, and a high quality process require good governance. These are core principles in ”The Toyota Way”, the Toyota Way is a set of principles for Toyotas governance structure and production [20]. Quality relates to all sides of the financial market, one can measure quality in a holistic view of the entire market or break it down to smaller individual parts. Market quality is not the focus of

this thesis, but it is an important factor when discussing high frequency trading. Quality in high frequency trading can be narrowed down to code quality. Software code for HFTs or algorithms will not be investigated because of their secretive nature and because they are often proprietary. For the purpose of this thesis both algorithms and HFTs are considered as black-boxes, where the input/output and end result is analyzed. Quality is also an important factor of trading systems, and there seems to be an urgent need for better quality and quality management for trading systems. Good quality software is not necessarily synonymous with few errors, the entire product must be evaluated. For instance, if a statistical module in a trading application is very good, but the interaction with other systems and the user experience is poor one would probably not consider it to be a good quality product. Interaction with other systems is important for trading software, and especially performance. A software development process goes through a series of cycles, a simplified version of this is shown in figure 3.1.

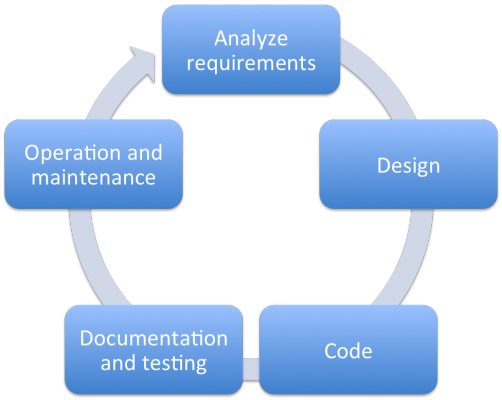

Figure 3.1: Simplified lifecycle of a software development process

The objective of Quality Management (QM) and Quality Management systems (QMS) is to achieve high quality output. QM and QMS provide guidelines and procedures for all the phases in figure 3.1. The operation/implementation phase has recently proved to need improvements, and in some cases the problems might trace back to earlier phases.

3.1.2 Stakeholder theory

Stakeholder theory is a contested concept in academia, and a widely acknowledged definition seems to be unachievable. The most cited definition of a stakeholder is Freeman (1984): ”any group or individual who can affect or is affected by the achievement of the organizations objectives” [21]. For a financial institution the organizations objectives is usually financial result/profit, which means capital return for investors. Stakeholders are found both within an organization as well as outside the organization, normal stakeholder are employees, owners (investors) and society [1]. Inside members or stakeholders contribute to the results with their creativity, knowledge, competence and

professionalism, where their contribution carried out through empowerment or delegation. Society is a stakeholder for many reasons and one them are job creation following a company that runs well. As an example, Apple has by 2012 created directly or in-directly over 300 000 jobs in the US [1]. If that same company starts loosing money, society will suffer from layoffs and increased unemployment. Brought to a head, this will negatively affect the entire economy and social welfare for an entire nation.

Identification of stakeholders is an important element for quality and quality management. The process of developing a good quality product should always take into account key stakeholders to unveil potential issues related to individual stakeholders. This is definitely not an easy task for trade related software, but still highly desirable. Stakeholder theory will primarily be used in relation to quality and quality management in this thesis, but also as a basis for important questions related to governance. A trading strategy or trading technique will affect many stakeholders and some of these might be hard to identify because of a thin relation or indirect connections.

An early draft of a stakeholder list is provided below, the list is random and not prioritized in any way.

- Developers
- Trading counterparts
- Company owners/investors
- Employees
- Traded companies
- Development firm (company that delivered software)
- Clients/Customers
- Trading venues
- Society
- Authorities/government
- Third party service providers (ISPs, hosting partners etc)
- Regulators
- Law enforcement

The example list of stakeholders show that there are many stakeholders to consider and the type of stakeholders is also diverse. Some might have third degree connections, meaning that they are connected by other stakeholders.

[1] http://www.apple.com/about/job-creation/

Law enforcement is one example, they are not directly affected by an organization's trading strategy but will be directly connected if regulators find irregularities that need further investigation. Others are directly affected, for instance customers, owners, investors and traded companies. Society is perhaps one of the easiest to identify, but the affects on society might be difficult to predict.

3.2 Interviews

A strong contributor to the scientific work in this thesis is qualitative interviews. The interview subjects chosen represent three different sides of the market and face high frequency trading on a daily basis. Comments and opinions from these interviews will be referenced throughout this thesis, none of the interviews will be reproduced in its entirety. The form of the interview was chosen because of the diversity of opinions among market participants. Quantitative interview and surveys are two other possible approaches and both would perhaps give valuable information in empirical research. These two types would most likely be interesting when evaluating more financial related topics and aspects. The focus of this thesis is not empirical research and is not written in a financial studies context, this thesis looks closer on a selection of aspect regarding high frequency trading. Opinions and statements from the interview are highly subjective, which means they must be interpreted and contextualized. Interviews will been conducted with the following organizations and people.

Oslo Bors is the only stock exchange in Norway. Norway is not part of the European Union, but is part of the European Economic Area, and is therefor included in MiFID. The staff of Oslo Bors is geographically located in the city of Oslo, but their trading systems are located in London. In 2009 Oslo Bors signed a cooperation agreement with London Stock Exchange, and in 2010 Oslo Bors successfully migrated to the same trading platform as LSE. Oslo Bors will be represented in interviews by the following people.

Thomas Borchgrevink is responsible for "Market Surveillance and Operations" at Oslo Bors. He has 15 years of experience working for Oslo Bors in various positions. In his current position he has in-depth knowledge of trading activity, and experience high frequency traders on a daily basis.

Eirik Finvold is the "Head of Trading Systems" in the Oslo Bors IT department. He started as a developer at Oslo Bors in 2008, and has been in his current position since 2011. Finvold sees high frequency trading from a technical view and has extensive knowledge about trading systems and how they interact with high frequency trading. He also has experience with monitoring solutions on Oslo Bors, and how these systems operate and function.

Norges Bank Investment Management (NBIM) is the asset management unit of the Norwegian Central Bank, one of their responsibilities is managing the Government Pension Fund Global (Norwegian Oil fund). The Norwegian Oil fund is the worlds largest sovereign wealth fund [2], and at the time of writing the value is over 4,3 billion NOK. In the interview NBIM will be represented by Stle Vilming and Malin Norberg. Vilming is titled "Head of Trading Strategies - Equite trading" and Norberg "Analyst - Equity Trading". NBIM is present in markets all around the world, and represent the investor side of the market.

Peder Veiby To get the perspective of a smaller market participant, an interview with a day-trader will be conducted. Peder Veiby is one of the defendants in the Timber Hill trial in Norway in 2010, and therefor has intimate knowledge about high frequency trading. Veiby has a background of economic studies and is currently self employed focusing on his trading activities.

[2] http://www.ft.com/intl/cms/s/0/3eb80a72-ae4a-11e2-8316-00144feabdc0.html

Chapter 4

Analysis and Synthesis

In the analysis chapter an evaluation of the current state of high frequency trading is given. This included analysis of current and historical work by regulatory entities both in the US and Europe, and also an analysis of the outcome of regulator work. Two of the most important upcoming and pre-released regulations in Europe and the US is comprehensively evaluated.

4.1 Authorities and regulation

The boundaries for market participants are generally defined by regulatory entities through laws and regulations. Governments and other authorities supervise and regulate the financial market to make the global financial system function. In regards to HFT there is no exception, but the authorities struggle to keep up with development speed of the modern market. Through a series of incidents both in the US and other parts of the world, authorities have proven that they do not possess the knowledge and expertise required to handle HFT related problems. The SEC and CFTC report from the "Flash Crash" was released over four months after the event, and in Norway the police investigated for about two years before the court trial. These two cases are not comparable, but they both show that authorities struggle to keep up with the technological advancements in financial markets. The trial in Norway was in the early stages of high frequency trading, but the "Flash Crash" occurred when high frequency trading was well established as a trading strategy or trading instrument. The situation today is slightly better, much because of the events of May, 6 2010, and authorities work hard to regain control of the fragmented and complex markets.

4.1.1 US

One must appreciate the irony of cause and effects for regulatory entities in the US. When Reg NMS was implemented in 2007 it provided strong incentives for highly automated trading facilities and new opportunities, like HFT, emerged. Now these very same regulatory entities are struggling to keep up the technology that has emerges in that very same market. The first step of

creating regulations for high frequency trading is to make a proper definition. CTFC has appointed a working group that includes representatives from CTFC and major market participants like NYSE, Deutsche Bank Securities and TABB Group [9]. The draft definition from June 2012 takes a quite broad approach to the subject of HFT and it has been criticized for being too broad. Some market participants are concerned about being captured by the definition because they operate with algorithms in the market. Why is the scope of the definition so wide? And are the CFTC deliberately trying to capture as may market participants as possible with this definition?

For the future progress of regulating HFT, the wide scope may cause problems because it captures too many firms. The few who have been bold enough to be outspoken about this is probably just the tip of the iceberg. Many of these firms captured by the definition might not define their own trading strategies as HFT, and it will be in conflict with the definition. The outcome of work of the CFTC and SEC is still unclear and this is probably why some firms are concerned, uncertainty is not what you want to present to your investors. One probable outcome of the HFT regulatory discussion is new registration requirements. The question is how this will affect firms operating within the CFTC definition of HFT. Entering the world of high frequency trading is a high cost investment, the hardware and services required to be fast enough, and therefor competitive, is expensive. If new regulations require even further investments to be compliant then it will most likely prevent all smaller firms from using high frequency trading strategies.

The vice president of Progress Software recently said: Weve managed over the past few years to equip the traders with Ferraris, and the regulators are trying to keep up with them on bicycles [1]. Besides the lack of expertise in regulatory entities, one of the biggest problems is the progression of creating regulations for HFT. There has been many meetings, working groups, roundtables and hearings, but so far the direct outcome has been absent. It is understandable that US authorities do not want to make premature decision and damage the most liquid market in the world by doing so. US authorities should have a big incentive to maintain their position as the most liquid market, and at the same time promote a fair trading environment. But the fact of the matter is that HFT is still not regulated, even though HFT has been present in the markets for quite a few years. Of course the amount of incidents solely caused by HFT are not that many, but if we include other types software related incidents the list much longer and much more expensive. There are many other aspects to the US markets other than problems related to HFT, this includes market fragmentation, types of market access and the amount of order types. Issues related to US market structure and other market specific details are frequently referred to by people promoting HFT and is often used to defuse and obscure HFT related problems. This is ironic. When considering the immense speed of HFT and the problems they bring. If the market structure is non-optimal and

[1] http://www.nytimes.com/2012/03/29/business/mishap-at-bats-stock-exchange-is-indicative-of-market.html?pagewanted=all&_r=0

so complex there should be an even bigger worry about the consequences of a rouge algorithm or poorly programmed HFT.

On March 5, 2013 media reported that the FBI and the SEC have joint forces to "fight" high frequency trading [2]. It is not the first time these two agencies work together, they have successfully been working together for the last three and half years. This collaboration indicate a quite clear statement from the authorities, high frequency trading will be under scrutiny from two powerful agencies. The involvement of law enforcements clearly dictates the approach taken by US authorities, but is this the best approach to challenges related to high frequency trading? High frequency trading have issues related to market manipulation, for instance momentum ignition, and market manipulation is illegal. This means that involving law enforcement would eventually be necessary to investigate market manipulation incidents. Perhaps it would be better, at this time, to focus on making clear regulations for high frequency trading, rather than pursuing high frequency trading firms which operates in an grey area of existing regulations.

The US market is known as the most liquid market in the world with the two largest stock exchanges in the world (NYSE and NASDAQ) [3]. US authorities acknowledge this and they will definitely try to keep it that way, which gives them a challenge when designing regulations for HFT. Considering the high trading volume and liquidity HFT firms provide to the American market, it is highly unlikely that the authorities will push the brakes so hard that this liquidity is removed. There are debates wether HFT provide or take liquidity but the majority of research agree that HFT provide liquidity [22]. Essentially the authorities needs keep most of the liquidity provided by HFT firms, and at the same time create regulations to make them operate within legal and safe boundaries.

One the most important initiatives from the SEC since the flash crash of 2010 is the Market Information Data Analytics System (MIDAS), this systems was initiated in 2012 [4]. The purpose of MIDAS is to collect trading information data from markets in the US, this allows the SEC to investigate low-level details of incidents which previously was not possible. In addition to MIDAS the SEC voted in 2012 to established a consolidated audit trail (CAT), CAT requires all registered stock exchanges and SROs to keep an audit trail of trading activity [5]. These two systems differs in that MIDAS collect publicly available information and CAT collect non-public data. The non-public data includes data like when and where a trade was executed as well as the parties involved in the trade. In the creation of MIDAS the SEC has hired Tradeworx, an HFT firm, to provide the expertise and service needed [6]. The service Tradeworx

[2] http://www.ft.com/intl/cms/s/0/11b81d74-85a4-11e2-9ee3-00144feabdc0.html

[3] http://www.forbes.com/pictures/eddk45iglh/the-worlds-biggest-stock-exchanges/

[4] http://www.sec.gov/news/speech/2013/spch021913ebw.htm

[5] http://www.sec.gov/news/speech/2013/spch021913ebw.htm

[6] http://www.nytimes.com/2012/10/08/business/sec-regulators-turn-to-high-speed-trading-firm.html?pagewanted=all

provide to the SEC, and MIDAS, is their proprietary real-time data feed technology, which hopefully will give the SEC the same footing as the high speed traders. The two initiatives, CAT and MIDAS, are important and desperately needed, but they are still merely tools to analyze the situation regarding HFT. Both tools provides the SEC with a more granular and accurate perspective on the markets. It is however noteworthy that these two systems are implemented two years after the "Flash Crash" and over five years after HFT became a reality in the US market.

4.1.2 Regulation Systems Compliance and Integrity

On March 7, 2013 Chairman Elisse Walter of the SEC announced a new regulations targeting technological challenges facing US markets. "The rule would require entities essential to the smooth functioning of the U.S. securities markets to have comprehensive policies and procedures regarding their technological systems" [7]. This new rule is called Reg SCI, and stands for Regulation Systems Compliance and Integrity. The rule was filed to the federal register on March 25, 2013 and is currently in a public comment period, meaning that it is not yet effectuated. Reg SCI will supersede and replace SECs current "Automated Review Policy" (ARP) and established by two policy statements titled "Automated Systems of Self-Regulatory Organization". These two statements were issued in 1989 and 1991, and is voluntary to participate in, the SEC consider this twenty year old program to be a success. They have however acknowledge the limitations that follow the voluntary nature of the program, and is not aiming to make compliance with the ARP program mandatory.

Reg SCI has been created as a direct consequence of recent and historical event related to technological breakdowns in the market, with input from various debates and hearings. Many of the incidents are previously discussed in the background chapter, and as usual the events of May 6, 2010 highlighted as the root cause. The proposed regulation is not specifically targeting high frequency trading as such, HFT is not mentioned once in the 104 pages long proposed regulation. Even though the regulation does not mention HFT it is still widely covered by the scope of the regulation, namely all automated trading systems.

In the proposed regulation there is a new terminology, with new definitions to various aspects of market participants and the systems they operate. The definition of a "SCI entity" is: "SCI self-regulatory organization, SCI alternative trading system, plan processor, or exempt clearing agency subject to ARP." [23] Each subset of organizations explained in detail in Reg SCI, where some is defined in other documents, and others defined directly in Reg SCI. There are also new definitions related to IT systems within a SCI entity: "SCI systems" and "SCI security systems". SCI systems is defined as "all computer, network, electronic, technical, automated, or similar systems of, or operated by or on behalf of, an SCI entity, whether in production, development, or testing,

[7] http://www.sec.gov/news/speech/2013/spch030713ebw.htm

that directly support trading, clearance and settlement, order routing, market data, regulation, or surveillance". [23] This definition will cover more or less all electronic devices within a SCI entity. "SCI security systems" is defined as: "any systems that share network resources with SCI systems that, if breached, would be reasonably likely to pose a security threat to SCI systems". [23] This definition would cover any type of system remotely related and/or connected to a SCI system. The wide scope of these two definitions is "intended to reach all of the systems that would be reasonably likely to impact an SCI entitys operational capability and the maintenance of fair and orderly markets, rather than reaching solely SCI systems". [23] In addition to these definitions Reg SCI defines "SCI event", these are events within a SCI entity related to a SCI system or SCI security system. Reg SCI defines three types of events [23]:

System Disruption means that an SCI Entity is unable to maintain normal operation, SCI entities are required to ensure fair operation for all parties. System disruption includes loss of data, loss of entire systems, failure to meet SLAs, failure to timely and accurately disseminate market data and any type of queue in data flow.

Systems Compliance Issue "An event at an SCI entity that has caused any SCI system of such entity to operate in a manner that does not comply with the federal securities laws and rules and regulations thereunder or the entitys rules or governing documents, as applicable."

Systems Intrusion "Any unauthorized entry into the SCI systems or SCI security systems of an SCI entity".

Reg SCI is not targeting HFT as such, but takes a broader approach to address all software related problems in the US market. Although HFT might be the root cause of the entire technology debate in the US, the debate has during recent years been fueled by incidents with technology breakdowns. Examples like Knight Capital and BATS has made the general public very aware of the consequences of software errors in trading systems.

The SEC has summarized themes from debates, discussion and hearing regarding technological regulation: *... adherence to best practices, improved quality assurance, more robust testing, increased pre-trade and post-trade risk systems, real-time monitoring of systems and improved communications when systems problems occur [23].* There are a lot of good aspects in Reg SCI, and the above sentence covers many of the important elements in quality and quality management. Reg SCI will create a much closer relationship between authorities and market participants. Regulatory entities will now be a part of many additional processes inside a organization involved in trading. With Reg SCI the authorities will have much greater insight to an organization through a series of reporting requirements for different procedures and systems. Organizations affected by Reg SCI will be required to submit yearly reports on subjects like: performance and capacity testing, system disruption procedures and plans, testing of disaster recovery and business continuity plans. This will give regulators a

much more active role, in addition to better control. For organization already participating in the ARP program the transition to be Reg SCI compliant will probably not be huge deal, but others who are not participating may have an extensive process ahead. The process of becoming Reg SCI compliant is hopefully a learning process rather than a "meet-the-minimum-requirements-and-be-approved" process.

In the proposed rule there is a scoped defined for which types of entities that shall be compliant with Reg SCI, and according to the SEC there are 44 entities that will meet the definition of a SCI Entity in its current wording. Among the organizations which are not affected we find entities like market-makers (Getco/Knight Capital) and broker dealers. HFT firms are typically one of these two entities. In the preamble of Reg SCI there are several references to errors made by exactly the type of organization that is excluded in Reg SCI. There are risks connected with every type of advanced technology used in the market, and anyone utilizing this should have an appropriate framework and procedures in place.

Hopefully this will be changed and this type of market participants will be included, in fact everyone using advanced technology should be included. If Reg SCI is to have any effect on high frequency trading these two entities would need to be included. It seems that the SEC is afraid on putting too much responsibility and requirements on market participants other than exchanges/trading venues. Some of the requirements of Reg SCI is perhaps not appropriate for all types of market participants, some of the rules specifically target trading venues. If other types of market participants were to be included the SEC would have to rewrite or rephrase some parts of Reg SCI. If the SEC has a goal of creating a technologically stable market they need to include everyone, not only the entities who are responsible for processing orders, but also entities who sent the actual order.

A high quality market is a stable market, and a stable market is beneficial to everyone participating. With Reg SCI the SEC has realized that quality and quality management is needed in the US market. The focus on quality is consistent throughout the entire proposed regulation, it covers phases from development and testing to disaster recovery. The focus on quality is highly appropriate and timely, this has been proven too many times in the recent past. The question is if Reg SCI is sufficiently clear and concrete enough to achieve the desired effect? In the proposed rule there are several references to standards developed by NIST and other organizations. These standards are however only referred to as starting points and/or reference material for developing own standards, SCI entities is under no obligations to actually use standards. Additionally the SEC does not provide any detailed information on any minimum requirement for standards required to be SCI compliant. So even though Reg SCI promotes and seeks high quality, it does not provide a clear path to achieve high quality.

As mentioned above the SEC seem reluctant to include all types of market

participants, and this gives them a problem. How can they achieve high market quality when only 44 entities are obliged to be SCI compliant? The total number of entities in the US market by far exceeds the 44 covered by Reg SCI, so are these 44 solely responsible for market stability? The 44 entities are off course a selection of the most important market participants, including the 13 registered stock exchanges and range of other alternative trading systems. But none of these can assure that no other market participant has software errors in their systems, they can only hope that their volatility prevention mechanisms protect everyone else if something goes wrong.

Governance is also an important aspect of Reg SCI, even though it does not specifically target organizational structure as such. Reg SCI does however require appropriate procedures and policies for an SCI entity, and both of these are cornerstones of corporate governance. Additionally Reg SCI has clear directions of communication requirements for an SCI entity, which relates to SCI incidents and the reporting requirements. An SCI entity that has a well established corporate governance will be much better equipped to be compliant with Reg SCI, and many of the existing procedures can be reused for SCI compliancy. Although there are shortcomings with the newly proposed Reg SCI it is undeniably a very good starting point and a huge step in the right direction to regulate technological aspects. It remains to see how it received and what feedback the SEC get from commentators. Further, how the final wording of Reg SCI will be and what effect it actually will have after implementation. At its current state the regulation will contribute to a more stable market, but the question is if they could do better/more? There is a good chance that Reg SCI is the start of a much closer collaboration between authorities in the US and market participants.

4.1.3 European Economic Area

As in the US, high frequency trading is subject to a widespread regulatory debate in Europe. Also similar to the US there is not a conclusive definition of high frequency trading in Europe, it is still a provisional definition. ESMA consider the definition to be broad, even though the definition of HFT is much more concise than the CFTC working definition [8]. Establishing a definition is the first important step in creating guidelines for high frequency trading, the definition limits the scope of the guidelines. ESMA kept its definition when releasing their guidelines on automated trading in 2011. These guidelines forms the basis of how automated trading should be regulated and will be included in MiFID II.

Although ESMA acted quite early to regulate automated trading, some countries in Europe felt they needed to further regulate high frequency trading. There are for instance an ongoing regulatory discussion in Norway about HFT, but they will probably await the release of MiFID II. In Germany they saw the need to further regulate high frequency trading. On March 22 2013 the German Bundesrat approved a high frequency act (”Hochfrequenzhandelsgesetz”) [24] [25]. This act extends the requirements of the ESMA guidelines and

gives German authorities a much tighter grip on high frequency traders. Key features of the German act:

- Authorization requirements for companies involved in high frequency trading. Companies who undertake high frequency trading must be licensed and authorized by the authorities.
- Order-to-trade-ratios (OTTRs) and minimum tick sizes are required for trading venues.
- Organizational requirements for high frequency trading firms. Requirements covers business continuity systems and risk management to ensure orderly operation and to avoid market disruption. This includes elements like trading system resiliency, capacity, thresholds and limits.
- Trading venues must electronically identify and tag any order submitted by an algorithm.

The Germans has taken high frequency trading very seriously and acts proactively. The example set by the German authorities is perhaps an example to follow for the rest of Europe. One the reasons why the German decided to adopt the high frequency trading act is probably due to the slow moving progress of MiFID revision 2. Revision MiFID is an ongoing process and the latest text was released in April 2013 and it is still a draft. Completion and implementation is still in the future.

4.1.4 Markets in Financial Instruments Directive 2

The work with a new revision of MiFID has been ongoing since the financial crisis in 2008. The first draft of MiFID 2 was published in 2011 [26], and the most recent text for MiFID was release in April 2013. The revision of MiFID is one of the ”key work streams” for ESMA in 2013, this probably mean that a realistic timeline would be implementation in couple of years [27]. One of the primary concerns of ESMA after the financial crisis was weaknesses in corporate governance, and governance is a recurring topic in MiFID 2. In addition ESMA clearly has algorithmic and high frequency high on their agenda for MiFID 2, in the background section of the most recent text they state that:

”These potential risks from increased use of technology are best mitigated by a combination of measures and specific risk controls directed at firms who engage in algorithmic or high frequency algorithmic trading technique and ...” [26]

There is an interesting formulation in that sentence, ”best mitigated” and ”directed at firms”. It seems that ESMA will try to move much of the responsibility for risks introduced and connected to high frequency trading away from the trading venues and over to each individual firm involved in high frequency trading. This approach is quite the opposite of the approach taken by the SEC in Reg SCI, where SCI entities (trading venues) are the primary target.

MiFID covers many aspect besides high frequency trading and governance and comparing MiFID to Reg SCI is not fair. Reg SCI is a specialized regulation for IT systems and does not cover any other market related topic unless they are connected to SCI. There are however some areas where they cross paths and are comparable, and both are designed with the same objective in mind, creating a stable market.

Article 17 in MiFID covers "Algorithmic trading, market making and direct electronic access", where high frequency trading is a subcategory of AT [26]. In this article there are 7 guidelines related to algorithmic and high frequency trading, and the eighth rule states that ESMA shall develop draft regulatory technical standard for rules 1-7. The technical draft standards can be found in ESMAs key objectives and priorities for 2013, it has "1-high" priority and expected delivery Q4 2013 [**?**]. This standard will define premises for high frequency trading in Europe in the future, and will be an important document for HFT firms in Europe. It will also affect US based firms that operate in Europe. ESMA has clear view on responsibilities when introducing new risks in the market by taking advantage of technological innovation, the risks associated with new technology lie with the firms or organization using the technology. The interesting aspect of this is that the responsibility connected to risks introduced when operating with HFTs and algorithms now lie with its respective firms rather than on the trading venue. Previously there has been very little responsibilities for HFT firms, ensuring market stability has been within then obligation of each trading venue.

To limit the amount of excessive messages MiFID 2 proposes to implement Order-To-Trade-Ratio (Order-To-Execution-Ratio). Article 51 - 3 in MiFID 2 state that:

Member States shall require a regulated market to have in place effective systems, procedures and arrangements to ensure that algorithmic trading systems cannot create or contribute to disorderly trading conditions on the market. At least Member States shall require regulated markets to have systems to limit the ratio of unexecuted orders to transactions that may be entered into the system by a member or participant, to be able to slow down the flow of orders if there is a risk of its system capacity being reached and to limit the minimum tick size that may be executed on the market [26].

This countermeasure for excessive messages will apply a fee if an order is cancelled or changed a sufficient amount of times. OTTR will positively affect some of the primary challenges with HFT like "quote stuffing". OTTR is already in place on various trading venues in Europe and in the US [8], Oslo Bors implemented Order-To-Executed-Order (OEOR) on September 1, 2012. The threshold they use is 70 to 1, and the charge is set to NOK 0,05 [28]. OTTR or OEOR is also used in the US [9]. OTTR will easy the operation and capacity of a trading venue substantially because the excess messages are removed

[8] http://www.efinancialnews.com/story/2012-04-02/how-to-get-your-ratios-right
[9] http://www.nasdaqtrader.com/TraderNews.aspx?id=ETA2012-13

and capacity of the trading venues is freed. With fewer cancellations it will also be easier for market participants to ascertain current prices and the true depths. It will however affect an already fragmented situation, where market participants posts orders on multiple venues and cancellations comes as a natural effect of this. There is very little academic research on the affects of OTTR [29], but there are certainly trading venues who possess information about the effects.

Another disputed countermeasure for HFT is "minimum resting times". The proposed rule state that:

"Member States shall require a regulated market to have effective systems, procedures and arrangements in place to ensure that all orders entered into the system by a member or participant are valid for a minimum of 500 milliseconds and cannot be cancelled or modified during that period." [26]

This rule will contribute to making better estimates of market price, and improve market quality by removing the "quote flickering" phenomenon. "Quote flickering" occurs when an order is rapidly changed causing uncertainty among other market participants who try to determine the price. Minimum order lifetime might seem counterproductive for technological advancements. HFT firms who have invested large amounts of money in high performance hardware will be left with unnecessary expenses, and the competitive advantage of HFT will also be severely reduced.

MiFID 2 addresses many of the problems with HFT, but it is criticized for attacking the problems med HFT from a wrong angle. Some commenters say that the main problem is that these rules are made by politicians [10]. Politicians do have the final vote regarding the text of MiFID 2 but market participants still have the opportunity to express their views and comment on the proposals. The final wording of MiFID 2 is still not established, but if ESMA adhere to their schedule it should not be too far away. The big question is how MiFID 2 will affect the market. Will HFT firms be forced out of the market? Will that improve market quality? Will HFT firms move their trading over to Dark Pools? Is that a good or bad? Is removing HFT all together desirable? Pushing the brakes too hard on HFT with MiFID will cause technological advancements to move in the wrong direction. There is no point in investing millions in high performance hardware if the authorities does not allow for high speed trading. Perhaps the critics are right when they claim that the wrong people are making the rules. There is no doubt that high frequency trading needs to be regulated, but not to the point of extinction. There must be better ways to accomplish fair and stable trading environments.

[10] http://www.bankingtech.com/81761/mifid-ii-is-a-dogs-dinner-says-former-uk-government-advisor/

4.2 Volatility prevention

4.2.1 Circuite breakers

Circuit breakers has been operational in the US markets since 1988, and was initially a response to the events of October 1987, known as "black monday". Market-wide circuit breakers was created in the aftermath of this event. Following the "Flash Crash" of 2010, Single-stock circuit breakers was created and began its first of three trial stages in June 2010 [30]. Since then there has been several revision of circuit breakers related to thresholds and other properties, where challenges related to circuit breakers seem to re-surface each time there is a large scale incident. Circuit breakers halt trading if triggered and MWCB have until recently been based on DJIA, where a reference trigger value has been calculated each calendar quarter. MWCB are triggered based on price movement and have three different thresholds: 10% (Level 1), 20% (Level 2) and 30% (Level 3). If the price moves outside these thresholds (up or down), trading will halt. The duration of the trading stop depends on the level that was triggered and at what time of day the circuit breaker was triggered. On February 4, 2013 the MWCB was changed. After February 4 MWCB use the broader S&P 500 Index as a reference index, and the thresholds have been changed to: 7%, 13% and 20%. The duration of trading halt when triggered has also been changed, and the reference trigger value is now recalculated on a daily basis. See table 4.1 and 4.2 for details of MWCB before and after February 4, 2013 [31].

Table 4.1: Market Wide Circuit Breakers - trigger , time and action for the US market, before February 4 2013.

Trigger	Time	Action
Level 1 (10%)	Before 2:00 p.m.	Halt 1 hour
	At or after 2:00 p.m. but before 2:30 p.m.	30 minutes
	At or after 2:30 p.m.	Trading continues, unless level 2 halt
Level 2 (20%)	Before 1:00 p.m.	Halt 2 hours
	At or after 1:00 p.m. but before 2:00 p.m.	1 hour
	At or after 2:00 p.m.	Trading halt and not resume for the rest of the day
Level 3 (30%)	Any time	Trading halt and not resume for the rest of the day

When the SEC updated the MWCB earlier this year, they made some major changes to the previous thresholds and properties. The most important change is probably the shift from DJIA to S&P 500, where the latter is more encompassing with a higher number of companies included. The trigger levels has also been adjusted and the time of day has been shifted further towards

Table 4.2: Market Wide Circuit Breakers - trigger, time and action for the US market, after February 4 2013.

Trigger	Time	Action
Level 1 (7%)	Before 3:25 p.m.	Halt 15 minutes
	At or after 3:25 p.m.	Trading continues, unless there is a Level 3 halt
Level 2 (13%)	Before 3:25 p.m.	Halt 15 minutes
	At or after 3:25 p.m.	Trading continues, unless there is a Level 3 halt
Level 3 (20%)	Any time	Trading halt and not resume for the rest of the day

the end of the day. Since this change was made only a few months ago there has not been recorded incidents where circuit breakers of any level being triggered. One other noticeable change is the duration of a trading halt, this has gone down from 1 and 2 hours to a flat 15 minutes for both level 1 and level 2 triggers. The commenters on the SEC filing for MWCB [31] felt that 15 minutes would be sufficient to assess a situation if a circuit breaker is triggered. 15 minutes trading halt would also be far less disruptive than the previous trading halt duration. The reason why circuit breakers on level 1 and 2 do not apply to the last 35 minutes of a trading day is to avoid disrupting "normal" market close at 4:00 p.m. Although it appears that a "normal" close would preferable, it is theoretically possible for the S&P 500 index to drop 19,99% just before the market closes without triggering a market-wide circuit breaker. Hopefully this would be impossible because other single-stock circuit breakers will be triggered.

Table 4.3: Static price monitoring at Oslo Stock Exchange

Groups	Limits
Stocks that are members of the OBX index (25 most traded securities in the OSEBX Index)	+/-15%
Stocks in liquidity segment Match	+/-20%
Stocks in liquidity group Standard/Oslo Axess/Equity Certificates and New stocks	+/-25%
Penny stocks with value less than NOK 1	+/-50%

In Europe circuit breakers have, like in the US, existed for decades. But in Europe there has been no incidents with a magnitude as seen in the US. Circuit breakers are probably not solely responsible for this, but has contributed to a stable and fair operation of European markets. That said, it must be acknowledged that the structure of the European market is different from the US. There has been incidents that have reached the general public, one of these event happened only three months after the "Flash Crash". On August 24, 2010, circuit breakers was triggered on London Stock Exchange, and according to news

articles this prevented a wider market crash [11] [12].

Listed in table 4.4 are the values for static price monitoring on Oslo Bors, these are the equivalent to single-stock circuit breakers in the US. As the table shows there are differences based on liquidity, where the 25 most traded stocks on Oslo Bors have the lowest threshold. This way of differentiating is not unique to Oslo Bors, it is quite common across European markets, and Oslo Bors usually follow practices from LSE. Note that the trading halt duration is not listed, both the duration of a trading halt and static price monitoring thresholds vary among individual stock exchanges in Europe. The duration varies from 2 minutes and upwards to about 15, on Oslo Bors the default duration is 5 minutes. Thresholds are usually found around +/- 5% from 15% [32]. The most significant difference between circuit breakers in Europe and the US is that the MWCB does not exist in the European market. Single-stock circuit breakers are however not the only volatility prevention mechanism in Europe, more on that in the next section about "Dynamic price monitoring and limit up-limit down". Market surveillance reports from Oslo Stock Exchange reveal that circuit breakers are frequently triggered and trading is also frequently halted for other reasons [33]. This information is absent, or at least, hard to find for US exchanges. One of the few who provides such information is NASDAQ, although only for the last month. A search through their database shows that trading halts do occur, but at a much lower frequency than at Oslo Bors. This is consistent with statements from the market surveillance team at Oslo Bors. According to them trading is halted almost at a daily basis. On Oslo Bors trading halts are automatically triggered by their surveillance system, and match making is put in auction for a five minute period. This gives time for the market surveillance team to determine wether trading should resume as normal when the auction period has passed, or if the situation require more investigation and normal trading should be further delayed.

Automatic volatility prevention tools, like circuit breakers, are effective and a necessity in modern markets. The timeframe for teams responsible for controlling trading environments has been lowered single-digit milliseconds, which makes it effectively impossible for human operators to react in a timely fashion. One of the drawbacks with using circuit breakers is an effect known as "magnet effect". This occurs when a circuit breaker approaches its threshold for trading halt, where market participants rush to get out of a liquidity position before the circuit breaker is triggered [34]. This behavior will severely accelerate an already declining situation, and might exacerbate an already bad situation.

The "magnet effect" is however hard to prove and distinguish when the market is already declining. It would have been an interesting experiment to see how circuit breakers will respond in a high stress situation. Although

[11] http://www.telegraph.co.uk/finance/markets/7963202/Circuit-breakers-kick-in-to-halt-strange-trades-on-London-Stock-Exchange.html

[12] http://online.wsj.com/article/SB10001424052748703447004575449752677529386.html

MWCB has existed for the last two decades, they have not been triggered on many occasions. They were triggered on one occasion in 1997, but during the ”Flash Crash” in 2010 they were not triggered. Circuit breakers operate both on single-stocks and market-wide, which means that monitoring systems at an exchange would have to keep track of large amounts of information. Given the speed of how a single stock is traded with HFTs the timeframe to react for an exchange is extremely low. What will happen if circuit breakers are triggered for a range of stocks traded by HFTs? How will a trading platform, and more importantly how will monitoring system handle such a situation? Further, how does HFTs react to trading stops?

Perhaps the first things that will happen in such a situation is that regular investor with human traders immediately pull out. This was one of the first reactions during the ”Flash Crash” and caused liquidity to vanish. Unusual and unexpected events are usually not a good thing for the human mind, and many will probably await the situation to try understand what is happening. One good example of this happened very recently. On April 24 2013 the Associated Press Twitter account was hijacked and a false message about an attack on President Barack Obama was released. This caused the S&P 500 index to drop 1 percent before quickly rebounding, $136 billion vanished momentarily from the market [**?**]. HFTs does not have the same abilities to reassess a situation in the same way a human trader is. How will an HFT react if trading is halted on stock that the HFT is trying to get out of? Will it flood the market with sell orders shortly after trading resumes? Perhaps this will trigger another circuit breaker and what happens then? The nature of HFTs imply that they will ”close out” at the of the day, but in the case of a trading halt they would be unable to do so. How does HFT firms respond to these situations? To avoid a situation where an HFT is stuck in an unwanted position one would have to closely monitor the trading activity and react if such a situation arise. Perhaps there should be a ”kill switch” for HFTs to make sure it does not try to overcompensate because of its liquidity position.

4.2.2 Dynamic price monitoring and limit up-limit down

Circuit breakers are not the only volatility prevention schemes. In Europe a scheme called ”Dynamic price monitoring” (DPM) has existed for years, London Stock Exchange describes this scheme as early as May 2000 [**?**]. A similar scheme named ”Limit up-limit down” (LULD) has very recently been implemented in its first test phases in the US, after it was filed on April 5, 2011. As the name of the European version indicates this is a ”circuit breaker” that has dynamic thresholds, both the European and the US version works more or less in the same manner. Stock prices are continuously monitored, reference prices calculated and thresholds are set based on this. See the figure 4.1 created by Oslo Bors.

As we can see from the figure the dynamic thresholds are continuously calculated throughout the trading day and follow a stocks price-movement.

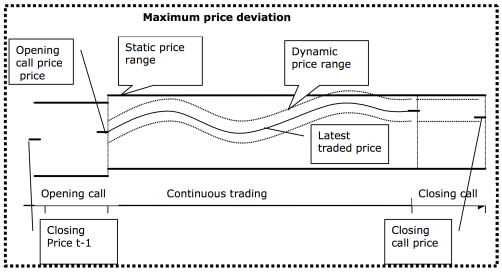

Figure 4.1: Description of static and dynamic price monitoring [35]

As opposed to the static thresholds which do not change during the day and the threshold is a flat line. For the US the reference price is calculated based on the arithmetic mean price of executed trades in the immediately preceding five minutes, if no trades has been made the reference price is unchanged. In the beginning and the end of a regular trading day the price band percentages are doubled. This is to ensure normal opening and closing, as seen with circuit breakers. When an order hits the upper or lower threshold it will be flagged as a "limit order". An order will exist the limit state if the entire size of all limit state orders are executed or canceled, if it does not exit the exchange will issue a trading pause for the stock in question. The trading pause is initiated by the primary listing exchange for the particular stock, and the pause will last for five minutes. The trading pause will apply to all trading venues where the particular stock is traded, this is different from how dynamic price monitors operate in Europe. Statoil is listed on Oslo Bors but if trading of Statoil shares is halted on Oslo Bors is does mean that it is halted on all other trading venues where Statoil is traded. The trading venues in Europe do however communicate and monitor each other closely, so trading might be halted under special circumstances but there it is not an automated action.

Phase I (Tier 1) – 9:45 AM to 3:35 PM	
Previous Closing Price	**Percentage Parameter**
Greater than $3.00	5%
$0.75 up to and including $3.00	20%
Less than $0.75	Lesser of $0.15 or 75%

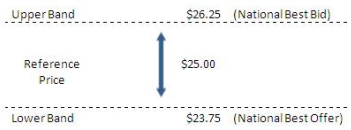

Figure 4.2: Limit up-limit down phase 1 parameter and triggers. [13]

The limit up-limit down pilot includes "tier 1" stock, this included all NMS stock listed on S&P 500 Index and Russel 1000 Index [36]. In phase 2, all stocks in the US are included, phase 2 is scheduled to initiate 120 days after phase 1. The intention of the limit up-limit down plan is to replace the existing single-stock circuit breakers, if the pilot program is successful. Unlike the US many

[13] http://exchanges.nyx.com/jonathan-jacobs/etp-update-limit-uplimit-down-and-market-wide-circuit-breakers

exchanges in Europe practice the use of both dynamic price monitoring and static price monitoring. Another major difference between the implementation in Europe and the US is that in Europe the order that breaks the limit does not enter a limit state. Trading for the particular stock will be immediately halted and trading will be set in auction mode for five minutes.

Table 4.4: Dynamic price monitoring at Oslo Stock Exchange

Groups	Limits
Stocks that are members of the OBX index (25 most traded securities in the OSEBX Index)	+/-5%
Stocks with fairly high liquidity and investment funds/ETF	+/-10%
Stocks with moderate liquidity	+/-12%
Oslo Axess/Equity Certificates/newly listed stocks and stocks with low liquidity	+/-15%
Penny stocks with value less than NOK 1/ETN	+/-50%

Unlike the US there is not a single common threshold for all exchanges and trading venues in Europe. Each individual exchange operate with its own thresholds, and many have different groups of stock with varying thresholds. The limits for dynamic price monitoring on Oslo Bors is displayed in table 4.4, parameters and thresholds for LULD in US is displayed in figure 4.2. Single-stock circuit breakers has been criticized for causing too many market disruptions, one example is a five minute trading halt following a single bad print. According to a report by Credit Suisse, there were 111 cases of single-stock circuit breakers triggered between June 2010 and September 2011 [37]. Of these 111 cases, only 12 occurrences were labeled as "truly disruptive", where all of these 12 were "fat finger" accidents. This is one the issues the SEC is trying to correct with the new LULD scheme, which is yet another result of the events of May 6, 2010. One interesting aspect of the LULD scheme is the fact that trading halt will be coordinated by the primary listing exchange and apply to all markets trading a security. This mean that in the world of high frequency trading you will be able to exploit latency. Theoretically you can trigger a circuit breaker on one exchange and keep trading the very same security on another exchange until the exchange is notified about the trading pause. This is just a theoretical example of one issue with LULD, but it brings us to the more delicate issues the US and the European market face.

4.2.3 Impact on market quality

Circuit breakers and "Limit up-limit down" schemes have certainly contributes to stabilizing the market and preventing excessive volatility. High volatile markets would not be considered as high quality markets, but in a more general and holistic view: have circuit breakers contributed to better market quality? Circuit-breaker and limit up-limit down schemes are undeniably necessary in the market, but only as a safety net when everything else fails. None

of these tools have had any affect on the recent market disruption, the underlying causes of these event extends far beyond the purpose and scope of these tools. They do not protect against software malfunction but might prevent an incident to escalate to an unnecessary level.

Chapter 5

Discussion and proposals

5.1 Moore's law

Moores Law famously states that the number of transistors in integrated circuits will double every two years. Murphy's law state that: "Anything that can go wrong, will go wrong" [1]. If we combine Moores Law with Murphys Law and transfer it to the financial market we get that: things that can go wrong, will go wrong, and it will go wrong very fast. The fact that things go wrong has repeatably been proven, and that it goes wrong very fast has also been proven on several occasions. From a system administrators point of view there are some issues with high frequency trading, but they are negligible compared to market complexity issues. As pointed out in almost every debate in the US there are other fundamental flaws with the market structure and other market specific flaws in the US. HFT has undeniably brought new challenges to the marketplaces, but these challenges do not originate from high frequency trading as such. The market, regulators and market participants were simply not ready to tackle technological advancements. The technological arms race is still ongoing and might create new unforeseen challenges in the future, perhaps FPGA is just the beginning.

Technology is constantly evolving, and maybe the lifetime of orders will in be measured in nanoseconds, rather than milliseconds, in just a few years. Technology will at some point be ready for these speed, but whether this would improve the world of trading will be up to others to decide. Perhaps the financial world should take a more modest approach in adapting new technology, and do thorough analysis before implementing even faster systems. During the "Flash Crash" people witnessed the true capabilities of high frequency trading and how fast liquidity can disappear (and re-appear). Other technological failures has also contributed to a general skepticism, and perhaps one of the major problems with HFT is the unknown. This in combination with authorities who seemingly do not have the control, the expertise or the systems required to oversee the modern market. Authorities and trading venues should work closely together to ensure that both parties acknowledge risks

[1] http://en.wikipedia.org/wiki/Murphy's_law

connected to implementation of new technology. Trading venues and market participant should perhaps also adopt a minimum level of transparency related to technical innovation. This would allow regulatory a level of insight into the fast moving technological arms race, and give them an opportunity to proactively respond.

The primary challenge for a system administrator in the financial world is to understand the complexity and the immense speed requirements. Maintaining systems that handle orders on a microsecond level is a challenge on its own, but the real challenge is understanding a larger complex system. Capacity planning is a key element in operating a trading system, this element was underestimated by NASDAQ during the Facebook IPO. When Facebook was going public in 2012 NADAQ proclaimed that their systems were able to calculate opening prices in just 40 microseconds and that their systems were able to handle the huge amount of anticipated orders. The interest in Facebook was however so heavy that opening price calculations increased to five milliseconds as orders came flooding in to the system. NASDAQ reset their systems, but the problems still persisted for hours after the opening. The magnitude of the Facebook IPO is rare, but it shows how important capacity planning is. Another curiosity with the Facebook event was NASDAQs lack of a fallback plan. Facebook had one of the most anticipated IPOs for years with over $18 billon in projected sales, and this happened only two months after the failed IPO of BATS [2]. Both BATS and NASDAQ are technological sophisticated exchanges, and if anyone could handle large scale IPOs it should have been them. If none of these can cope with the requirements for a large scale IPO, then who can?

The ethical aspect of high frequency trading is diverse, motives and objectives depends on the stakeholder. NBIM is working on a paper which looks at the sociological aspect of high frequency trading, this is a very interesting perspective for many reasons. How is HFTs affecting society compared to "regular" trading? Does HFT firms have different ethics profile than other market participants? Are there positive sociological aspects with HFT? There are also other aspects to HFT firms other than the ethical aspects related to their trading strategy and techniques. Is the corporate governance different in HFT firms?

High frequency traders have for many years operated in a grey area not fully covered by regulations and rules. Trading techniques used in high frequency trading are well known and to certain point covered by financial law, but in many cases they "fly below the radar". This means that on a general basis HFT is covered by financial law, but HFT has other challenges following their superior speed. There are aspects of high frequency trading that would be highly unethical, for instance "ping orders" and "quote stuffing". Both of these would be considered as unethical, both aspects can be used in an unfair way for other market participants. "Ping orders" mostly occurs in "Dark Pools" to assess the market. If the intention is to conduct a transaction this might not be unethical, but it would still be bordering on unethical behavior.

This issue is more related to problems with dark pools and the way these operate rather than issues with HFT. ”Quote stuffing” would not be considered as ethical conduct. There are may reasons to perform quote stuffing, but these are not fair to other participants and is harmful for market quality.

5.2 Proposals

The following section describes three proposals to improve the situation of modern trading with high speed low-latency trading facilities.

5.2.1 Code inspection

People make mistakes, that is a human characteristic. Programmers are no exception and eliminating all mistakes is close to impossible. People making modern software write many lines of code each day and there will inevitably be minor and/or major errors. Multiply this with the number of people working with a particular software project and the result will eventually be flawed. Combining flawed software with a complex web of interconnected trading venues and extremely advanced mathematical algorithms will at some point end up in disaster. There has been few incidents with erroneous software just last year, and the question is how much more investors are willing to take part in.

HFT firms and companies developing their own algorithms have large departments and teams working on this aspect of their trading. For successful firms, like Getco LLC, the people working in these departments are certainly intelligent and very good at what they do. But even though they are very good at their job, it might be healthy to allow a third-party to evaluate their code. Allowing a third party to analyze their code will contribute to identification of possible flaws and possible problems. Analyzing other peoples work is not an easy task, it would require highly skilled professionals that understands both programming and is able to see the bigger picture. In addition it would require mathematical skills to analyze any algorithms.

Figure 5.1: Code inspection might reveal mistakes

HFT firms will most likely be skeptical to allow others to review their software code and they have good reason for this. Code for HFTs would be very

attractive to other market participants, obtaining details about an algorithm and knowing how it responds will allow others to abuse an HFT. A good example of this is the Timber Hill case in Norway. The team analyzing code for a firm would have to be impartial and independent, non-disclosure agreements is an obvious requirement. The benefits of code inspection is three-folded: Mitigating risk for the organization it self. Removing software errors that could potentially lead to losses would reduce the risks of operating HFTs. Mitigating risk for other market participants. Software errors in an HFT operated by a company might affect trading in other organizations, where they suffer because of others mistakes. Stabilizing the market. Market disruptions affects everyone, and improving the stability of the market would also improve investor confidence in the market.

Code inspection does not only apply to HFTs, but performing an extensive review of proprietary code is time consuming. Reviewing other types of trading systems would also be valuable, but large trading systems is perhaps too much to cover. Larger trading systems would be easier to run through a series of standardized tests, as discussed in the following section about QMS. Code inspection would probably fit best in a certification process before organizations are allowed to trade actively. There are obvious challenges related to do code inspection, first of which is the issue of privacy and corporate intellectuals. Another issues is the competence and skills required, who possesses the knowledge to do such an inspection? The people who do possess these skills are very attractive to firms developing software code for trading. These people will at some point be tempted to move away from reading other peoples work and make more money by developing software for trading firm. The upside to this is that people who have been involved in the proposed code inspection will be highly knowledgeable and be able to avoid any pitfalls others might not see. If we turn the table, the very same people might use their knowledge about other companies to steal code or even take advantage of any shortcomings. Code inspection might be a controversial suggestion, but from a technical view there very few drawbacks.

5.2.2 Mandatory quality management systems

Code inspection contribute to eliminate software errors, but does not safeguard against implementation and/or operational errors. A prime example of this is Knight Capital "glitch" in 2012, according to media sources the cause of this event was a new piece of software that was not installed correctly and conflicted with old code. Any competent IT person would raise the question if this glitch actually were a software bug or a procedural/human error. This situation could, and should, have been avoided in any case, and it shows a lack of quality management. Appropriate testing procedures and procedures for implementation would have helped the situation, at least to mitigating the incident. There is not doubt that most financial companies does rigorous testing of their systems before putting them into production. But there is obviously room for improvement. Some of the aspects related to testing is addressed in

Reg SCI, but these are only reporting and compliance requirements. In MiFID there is a testing requirement as a part of the governance requirements, and no specific rules directly targeting testing.

A testing phase is designed to unveil problems, and well designed tests will reveal the most serious errors. Commenters on proposed regulations often refer to the issues of fully testing an algorithm, and they often claim that it would be impossible to fully test an algorithm. This might be true, but there are ways to test even the most advanced algorithm, even if you do not understand the algorithms it self. To cover all possible scenarios an algorithm might encounter is impossible, it is too time consuming and predicting the future is still not possible. But there are ways to design highly advanced tests and create real world scenarios with the help of two newly created initiatives. With CAT and MIDAS the US authorities have an excellent opportunity to use the data gathered with these two systems to create and simulate real world test-cases. These cases can be real events where algorithms are known to behave disorderly. It is also possible to use the data gathered to analyze algorithmic behavior, and use this information to push the limits of algorithms. Pushing the limits or stress testing an algorithm would perhaps help to avoid another situation like the "Flash Crash". AT9000 suggests that algorithms are verified and tested under stressed situations before released to the market.

AT9000 defines a quality management system directly targeting automated traders, high frequency trading would be considered as a subgroup of this. If QMS was compulsory for all market participant involved in HFT, or any form of automated trading, then the total systemic risk introduced would be reduced. AT9000 suggest implementation requirements of real-time monitoring systems and also kill-switches. These two suggestion are highly desirable, and should be carefully considered before they are discarded. Real-time monitoring systems are an essential part of the surveillance function on Oslo Bors, and is probably the most important individual component in the battle with high speed traders. Immediate action to irregularities is important to maintain a stable market, and the immediate action could be initiated by any parties involved in a trade. That mean both the sell-side and the buy-side in addition to the trading venue where the trade is executed.

There might however be a conflict of interest in adaptation of these two requirements. The term "fat-finger" is well known phenomenon in financial lingo, and it refers to a human error of pushing the wrong buttons or entering the wrong numbers. In such events there are always people making money of other peoples mistakes. HFTs have generally a low inventory, and the losses from a "fat-finger" event on a single HFT would in most cases be small. But what happens if the same error has been made on multiple HFTs or in multiple algorithms? Does market participants have the appropriate procedures and mechanisms to respond? It is obvious that the firms involved in the "Flash Crash" did not have the appropriate procedures in place, and regulators underestimated the capabilities of high frequency traders. None of the circuit

breakers were triggered, and trading continued even though there was dramatic decline in the entire market.

The benefits from using a quality management system, like AT9000 suggests, does not only positively affect systemic risks and market stability. Operational efficiency is another positive side of QMS. High quality products requires less maintenance (bug fixing). Employees will have to take control over their own processes and document their work, and when the outcome is a high quality then the amount of rework will be reduced. This will contribute to the overall efficiency of a company, and will positively affect customers (investors). Documented work and process will also contribute to make an organization less dependent on specific employees, it will be easier for others to familiarize themselves with peoples work. Documentation is also a key to identify potential errors and will contribute to make bug fixing processes less demanding. As a whole there are many benefits to ISO9000/AT9000, but there are also downsides. ISO 9000 has been criticized for being to costly and too time consuming, but several studies show that ISO 9000 reduce operational cost and improve financial performance [38] [39]. AT9000 is a modified version of ISO9000 and might be more appropriate for financial institutions as it has a very limited scope. And it will be very interesting too see wether or not the working group succeeds in creating a standard that financial organizations will approve of and implement.

ISO 20000 defines the concept of "acceptance testing" - the final stage before an application is put into production, this process is described by Sommerville (2011) [40]. This final stage is perhaps the most critical stage for a trading system, if this stage is underestimated a serious incident might occur. The goal of an acceptance test is to decide if a system is ready to be put into production from a customers point of view. When software is developed by an internal department there is no customer to perform the acceptance test. This if often the case with proprietary automated trading systems, these systems are developed inside an organization by an internal development department. In these cases the acceptance test should be performed by the people who are supposed to use the software, not by the same people who wrote the software code. This might be traders or other supervisors who are not directly involved in the development process.

Criteria's for the acceptance tests should be established early in the development process, perhaps as a part of the planning process. Transitioning a system from development to production also includes transitioning from a development department to an operations department. System administrators should perhaps also be included in the acceptance test, but does system administrators know what acceptance testing is? The chances are that they don't and this might be a results of their education, at least that is the case for system administration programs in Norway. The intersection between developers, system architects and system administrators is an important part of a successful process. As a minimum this intersection should be included in any

quality management system. It would have been even better if educational programs introduce students to this concept as a part of their education. This way they would be aware of the concept and could contribute positively to an implementation process.

5.2.3 Transferring responsibilities

The responsibilities of trading venues increase with the pace of technological developments, new and faster technology emerge and the trading venues must keep up to be competitive. Besides this they have most of, if not all, the responsibility regarding market volatility countermeasures. Circuit breakers and other requirements are frequently changed. So far in 2013 there has been two changes to volatility countermeasures in the US. The existing circuit breakers have been modified, and the pilot program for "limit up-limit down" has recently been initiated. Both of these require work for the exchanges, and rigorous testing before new schemes are put into production. In addition, the SEC recently released Reg SCI, which will impose even more requirements for trading venues. Why shouldn't some of the requirements be transferred to firms and organizations operating in the market? One of the objectives of AT9000 is to reduce systemic risks, and these systemic risk are not introduced by stock exchanges [16]. Why are market participants that introduce risks excluded from Reg SCI? IT people often speak of acting pro-actively, rather than re-actively, and this could be transferred to the world of trading. It should be possible to address many of the recent problems by moving some of the current responsibilities from the exchanges to the trading firms.

Chapter 6

Final thoughts and conclusion

6.1 Final thoughts

To completely understand high frequency trading and its implication one need to do a larger study and analyze various aspects on a more detailed and individual level. This include looking at market related challenged as well as the technology used. Challenges in the financial world are not created by technology, but market imperfections have been amplified by advanced technology. This includes aspect related to high frequency trading but also general software development and implementation issues. There are many areas of improvement, both related to technology and finance. Software development and software implementation has obvious potential for improvement.

The future of high frequency trading is at this point still unclear, but there are two major regulations that will form and set guidelines for the future. Reg SCI was recently released but is not yet approved or completed. The new revision of Markets in Financial Instruments Directive is also close to completion. These two have very different approaches, and if they are approved in their current wording it will be interesting to compare the outcome in the US and in Europe. Both of these will affect high frequency trading to a certain exent. Since they have different approaches there is a good chance that the outcome will be different. MiFID revision 2 is perhaps the most interesting of the two because is contains very strict constraints for high frequency trading. How this affect the trading landscape remains to see, but it would undoubtedly change the world of high frequency trading. The authorities in Europe and the US has a large task ahead in creating regulations to improve market quality. Perhaps the biggest concern for regulatory entities is the lack of an established and approved definition. Definitions of high frequency trading vary in reports, studies and among regulatory entities.

There is a need for academic and empirical research on the topic. Empirical research is difficult because of the complexity and fragmentation, but it should be possible for regulatory entities to initiate studies that will contribute to a better understanding. Better understanding is the key to make good regulation, and to make regulations that consider future advancements. Predicting

the future is obviously difficult but there are lessons to be learned from previous regulations. There are also many sociological questions that remains unanswered. Ethical aspects of high frequency trading has not yet been fully explored, ethical aspects are closely related to empirical research. Ethical aspects include the effect of high frequency trading on society and effects of HFT firms presence in the market. Research on how high frequency trading affect market quality should be conducted on larger scale than the existing studies. Studies are often limited to a single trading venue and does not include data from other exchanges. Market quality question like wether or not HFT provide or take liquidity and the affect on spread should also be further explored.

Different market access types remains unexplored in this thesis. Sponsored access, direct market access and proximity hosting are types of access that influences the use of high frequency trading. Colocation is probably the most interesting in this respect, but other types should also be explored to gain a holistic view. Also how trading venues provide or not provide certain types of access, how this influences the proportion of high frequency trading. Infrastructures around the world also influence the use of high frequency trading, comparing how infrastructures around the world contribute to the prevalence of high frequency trading would be of value. How the infrastructure is used also what types of infrastructures is dominant.

One of the goals of this thesis was to gain access to HFT software code. This has proven to be difficult, software code for advanced algorithms and HFTs is secretive and often proprietary. This means that if one could have reviewed the code it would have been a difficult task to analyze it. By looking at the code for HFTs one would probably be able to better understand the implications of their presence in the market. Also provide a perspective of the programming and how HFTs are created. There are several books on this topic, both on programming algorithms and creation of trading systems. None of these books have been explored or reviewed in this thesis. It could also have been interesting to speak with companies or individuals that provide software code for algorithms or HFTs. These companies would have had valuable information about the development processes and views on quality management. They could also provided information about requirements from their customers and described the procedures throughout a development process.

The interviews conducted in this thesis has been very helpful and fulfilled the intention. Market participants have different views and all the parties interviewed had valuable insight. A broader specter of candidates could have been selected, but the timeframe of this work was limited. A broader perspective might have obscured the central topics of this thesis. Market participants have very different views on what high frequency trading is and the application. This became evident in the early research phases after speaking with market participants. Interviews with HFT firms would also be valuable, but there are very few (if any) pure high frequency trading firms in Norway.

6.2 Conclusion

There are no simple answers to the challenges of modern trading, the challenges are far too complex. Challenges related to market structure might be hard to address and change without drastic measurements, but technological challenges are perhaps easier to address. Regulatory authorities has come a long way the last few months and newly released regulation show promise in improving market quality. New regulations show both a shift in the approach and a more targeted scope on automated trading. The focus on quality in IT systems is long awaited and will contribute to a higher level of quality in the holistic system. The focus on quality also benefits corporate governance amongst market participants, new regulations will lead to governance improvements that will overall benefit financial organizations.

In this thesis three proposals are given and suggestions on how regulatory entities can attack the problems they face. The proposals conform with the AT9000 standard under development, and many of the proposed rules of Reg SCI. AT9000 and the proposals are aimed at governance structures of financial institutions with a strong focus on quality and responsibilities. Some suggestion might be difficult to implement and organizations operating with automated trading might not be ready. There are however good opportunities to improve software and reduce market disruption by implementing quality management systems. Transferring responsibilities is closely related to suggestions in AT9000 that will enhance the awareness of market participants on the subject of quality. High quality markets is beneficial everyone and contributes to the greater good.

Chapter 7

Definitions

AQ - Automated Quotation, system that provides automatic quotation.

CFTC - Commodity Futures Trading Commission is an independent agency with the mandate to regulate commodity futures and option markets in the United States [1]. CFTC work closely with the SEC and other agencies in the US.

CME - Chicago Mercantile Exchange is an exchange were future contracts and future options is traded. For instance "E-Mini".

DJIA - The Dow Jones Industrial Average is an index based on how 30 large publicly owned companies trade during a standard trading day. DJIA has historically used for calculating thresholds for circuit breakers.

DMA - Direct market access are network links, typically provided by a broker/dealer or market marking firm, that allow other market participants to access a market under the trading firms identification code. When using this type of access all orders are routed through the market making firms trading system, and the market maker is responsible for all trades.

EBA - European Banking Authority is a part of European System of Financial Supervison. "EBA acts as a hub and spoke network of EU and national bodies safeguarding public values such as the stability of the financial system, the transparency of markets and financial products and the protection of depositors and investors. [2]"

EIOPA - European Insurance and Occupational Pensions Authority is a part of European System of Financial Supervison. EIOPA acts a the link between national insurance supervisor in the European Union.

ESMA - European Securities and Markets Authority is a part of European System of Financial Supervison. This systems consists EBA and EIOPA in addition to ESMA. ESMA oversee financial markets in Europe, similar to role of the SEC in the US. [3]

[1] http://www.cftc.gov/About/MissionResponsibilities/index.htm
[2] http://www.eba.europa.eu/Aboutus.aspx
[3] http://www.esma.europa.eu/page/esma-short

E-Mini - Is a future contract of a wide range of indexes, traded at CME. A future contract is an contractual agreement to trade at pre-defined price in the future. Future contracts have underlying assets.

ETF - Exchange traded fund, is a fund traded on exchanges much like regular stocks. ETFs consists of a variety of other trading assets like bonds, stocks and commodities.

FINRA - Financial Industry Regulatory Authority is an independent regulator for all firms operating in the US and the US stock market. FINRA is overseen by the SEC. [4]

FPGA - Field-programmable gate array is an integrated circuited, that is extremely fast and programmable to perform certain operations.

IPO - Initial public offering is the launch for a company to be traded publicly on the open market.

NASD - National Association of Securities Dealer is an SRO that was responsible for overseeing the NASDAQ stock exchange. Merged with the regulation committee of NYSE to form FINRA on July 30, 2007 [5].

NMS - National Market System - Facilitated by the SEC in 1975 to establish a national market system, linking together individual markets that traded securities. Many types of markets participates in the NMS, including listed stock exchanges, alternative trading systems and market-making securities dealers. [15]

SA - Sponsored Access is similar to DMA but differentiates in that orders are not routed through the market makers trading system, although orders are still submitted under a market makers trading codes. Order are routed directly to the Exchange and validated using systems provided by the Exchange itself.

SEC - Securities and Exchange Commission oversees the financial market in the United States. They are responsible for investor protection and facilitate capital information. Also to maintain fair, orderly and efficient market operation. [6]

SFTI - Secure Financial Transaction Infrastructure is a backbone network for securities trading. Created by NYSE Technologies, originated in the US and has later been launched in Europe and Asia. [7]

SOR - Smart Order Routing means that an order is routed to the trading venue offering the best price (NBBO).

[4] http://www.investopedia.com/ask/answers/112.asp
[5] http://www.sechistorical.org/museum/galleries/sro/sro06g.php
[6] https://www.sec.gov/about/whatwedo.shtml
[7] http://nysetechnologies.nyx.com/global-connectivity

SPY - SPDR S&P 500 ETF Trust (NYSE Arca: SPY), is an exchange traded fund (ETF).

SRO - Self-Regulatory Organization is a "non-governmental organization that has the power to create and enforce industry regulations and standards" [8]. FINRA and stock exchanges are examples of SRO's.

STP - Straight-Through Processing is the automatic process of an entire trade from initiation to payment and clearing.

S&P 500 - Standard & Poorss 500 is a stock index similar to DJIA, but as the name indicates, S&P 500 is based 500 companies instead of 30 as the DJIA. This index includes large companies in leading industries, for example: Apple, Exxon Mobile, Google Inc. and General Electric.

Trade through - Orders not executed at a best possible price. This kind of trade was eradicated by the "Order Protection Rule" in Reg NMS.

[8] http://www.investopedia.com/terms/s/sro.asp

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