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High Frequency Trading, Accident Investigation, and the 6 May 2010 Stock Market Flash Crash

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McLean, VA

Gary Vecellio
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Abstract

This paper describes a novel application of a system-based accident investigation method to the understanding of a complex financial system incident. STAMP (Systems Theoretic Accident Models and Processes) is used to model aspects of the flash crash of May 6th 2010. STAMP was applied to the E-Mini S&P 500 (E-Mini), a stock market index futures contract traded on the Chicago Mercantile Exchange's (CME) Globex electronic trading platform. The application of the STAMP method made it clear the E-Mini market lacked the level of control necessary for the market to be defined as a controlled process.

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1 Background

On May 6, 2010 the stock market opened lower on Greece debt crisis worries and trended down for most of the day. At 2:42 pm, the Dow Jones Industrial Average (DJI) (made up of 30 major American companies) began to fall rapidly. The DJI dropped an additional 600 points in 5 minutes for an almost 1000 point loss by 2:47 pm. Twenty minutes later the average had regained most of the 600 point drop, finally closing at 10520.32, down 347.80 points for the day. [6] While there are a number of potential causes for the 2010 flash crash, reports and surveys point to High Frequency Trading (HFT) as a contributing factor. HFT consists of directed, adversarial, autonomous algorithms (agents) that attempt to capitalize on millisecond changes in the state of financial markets.

A survey conducted by Market Strategies International between June 23-29, 2010 reports that over 80 percent of U.S. retail advisors believe that "overreliance on computer systems and high-frequency trading" were the primary contributors to the volatility observed on May 6. Secondary contributors identified by the retail advisors include the use of market and stop-loss orders, a decrease in market maker trading activity, and order routing issues among securities exchanges. [1]

Stability of the financial markets is further impacted by the heterogeneity and adversarial nature of participants, and the lack of systems engineering controls, within and between the participants.

However, the finance industry has not yet fully adopted high-standard systems engineering frameworks and process management approaches that have been successful in the software and manufacturing industries. Many of the traditional methodologies for product design, quality control, systematic innovation, and continuous improvement found in engineering disciplines can be applied to the finance field. [2]

Very few firms at the cutting edge, high frequency trading firms included, understand the true complexities involved when all of these algorithms are interacting with each other in the marketplace and the nonlinear incidents that happen, such as the Flash Crash. [3]

This "informal" approach to systems engineering is in stark contrast with the approaches used in other communities, most notably systems safety. The system safety community has developed and applied novel assurance and accident investigation approaches that supplement traditional reliability-based methods with methods based on system control theory.

This paper describes a novel application of accident investigation methods in an attempt to understand the system control issues that facilitated the 2010 flash crash.

1.1.1 Flash Crash

The unique aspect of the flash crash wasn't a large decline in prices - it was the inappropriate, out of control decline and subsequent recovery of financial instruments. For a period of time, financial instruments no longer reflected the underlying value of the companies; system control was lost.

On May 6, 2010, the prices of many U.S.-based equity products experienced an extraordinarily rapid decline and recovery. That afternoon, major equity indices in both the futures and securities markets, each already down over 4% from their prior-day close, suddenly plummeted a further 5-6% in a matter of minutes before rebounding almost as quickly.

Many of the almost 8,000 individual equity securities and exchange traded funds ("ETFs") traded that day suffered similar price declines and reversals within a short period of time, falling 5%, 10% or even 15% before recovering most, if not all, of their losses. However, some equities experienced even more severe price moves, both up and down. Over 20,000 trades across more than 300 securities were executed at prices more than 60% away from their values just moments before. Moreover, many of these trades were executed at prices of a penny or less, or as high as $100,000, before prices of those securities returned to their "pre-crash" levels.

By the end of the day, major futures and equities indices "recovered" to close at losses of about 3% from the prior day. [4]

In this paper we examine the E-mini, a stock market index futures contract traded on the Chicago Mercantile Exchange's Globex electronic trading platform, as a proxy for the stock market in general.

1.1.2 Systems Theoretic Accident Models and Processes (STAMP)

STAMP changes the incident investigation perspective from component failures to constraint enforcement.

… STAMP (Systems-theoretic Accident Model and Processes), changes the emphasis in system safety from preventing failures to enforcing behavioral safety constraints. Component failure accidents are still included, but our conception of causality is extended to include component interaction accidents. Safety is reformulated as a control problem rather than a reliability problem. [5]

STAMP uses a standard system control model that can account for software errors, human errors, component interaction accidents, and components failures (see Figure 1). Control is *inadequate* if the any of the following occur:

1. Required control commands are not given
2. Unsafe control commands are given
3. Required commands are given too early or too late
4. Required control action stops too soon or is applied too long

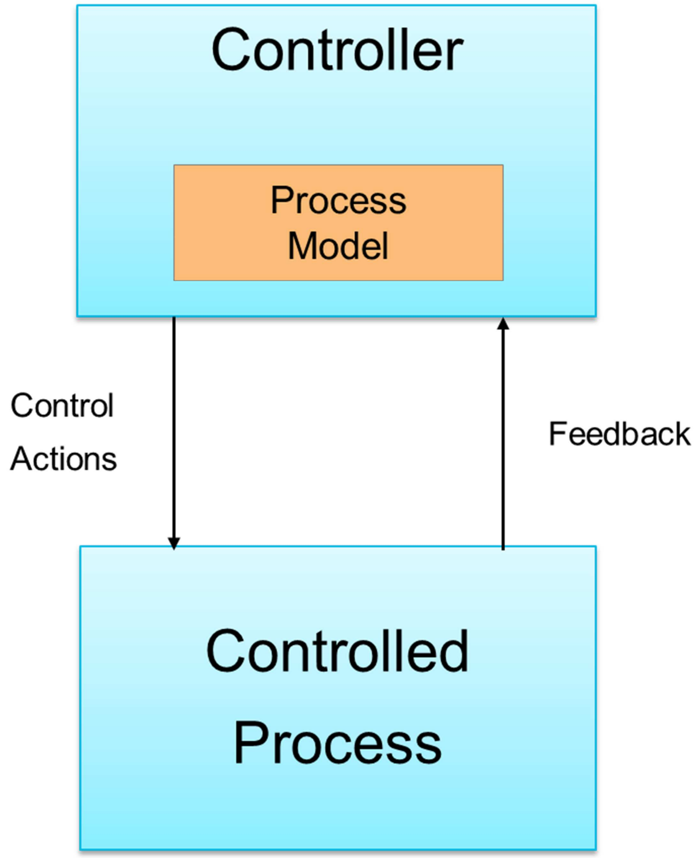

Figure 1: STAMP System Control Model

2 E-Mini S&P Market

E-Mini is a stock market index futures contract traded on the Chicago Mercantile Exchange's (CME) Globex electronic trading platform. The implied volume of the E-mini greatly exceeds the traded dollar volume of the 500 underlying stocks, which makes it a significant contributor to the overall market. While it is refuted by the CME, the US government asserts the sale of 75,000 E-mini contracts by a single trader was the trigger that caused the 2010 Flash Crash. [4]

2.1 Market Participants

In an analysis of the 2010 flash crash [1] the E-Mini market participants were classified as follows (the number in parentheses indicates the active participants on the day of the flash crash):

- Autonomous
  - High Frequency Traders (16)
- Automated
  - Intermediaries (179)
  - Fundamental Buyers (1263)
  - Fundamental Sellers (1276)
  - Opportunistic Traders (5808)
- Human
  - Small Accounts (6880)

Intermediaries are short horizon investors who follow a strategy of buying and selling a large number of contracts to stay around a relatively low target level of inventory. This class of market participants have the following characteristics:

- Direction: Buy or Sell
- Position: Long or Short
- Time Horizon: Short
- Holding / Position: net fluctuates +- 1.5% of end of day level
- End of day inventory: <= 5% of daily volume
- Strategy Constraints:
  - Capital
  - Inventory - mean reverting around zero
  - No market condition risk
  - No overnight risk

High Frequency Traders are a subset of Intermediaries, who individually participate in a very large number of transactions, top 7%. This class of market participants have the same characteristics as Intermediaries:

- Direction: Buy or Sell
- Position: Long or Short
- Time Horizon: Short
- Holding: net fluctuates +- 1.5% of end of day level
- End of day inventory: <= 5% of daily volume
- Constraints
  - Capital, relatively low
  - Inventory - mean reverting around zero

    - No market condition risk
    - No overnight risk

Fundamental Buyers are longer term traders that mostly bought on May 6th. This class of market participants have the following characteristics:

- Direction: Buy
- Position: Long
- Significant end of day position
- Time Horizon: Longer
- End of day inventory: >= 15% of daily volume
- Trading Constraints
    - Capital
    - Inventory
    - Market conditions
    - Overnight risk (due to large position)

Fundamental Sellers are longer term traders that mostly sold on May 6th. This class of market participants have the following characteristics:

- Direction: Sell
- Position: Short
- Significant end of day short position
- Time Horizon: Long
- End of day inventory: >= 15% of daily volume
- Trading Constraints
    - Capital
    - Inventory
    - Market conditions
    - Overnight risk (due to large position)

Opportunistic Traders both buy and sell around a target net position or accumulate a directional long or short position. This class of market participants have the following characteristics:

- Direction: Buy or Sell
- Position: Long or Short
- Significant end of day position
- Time Horizon: Hours -> Days
- End of day inventory: Varies
- Trading Constraints
    - Capital
    - Inventory
    - Market conditions
    - Overnight risk

Market participants can also be characterized by their degree of automation (see Figure 2). HFT algorithms interact directly with the CME Globex electronic trading platform. The strategies utilized by intermediaries, fundamental buyers and sellers, and opportunistic traders are implemented by automated trade execution engines. Small trader transactions involve human generated orders.

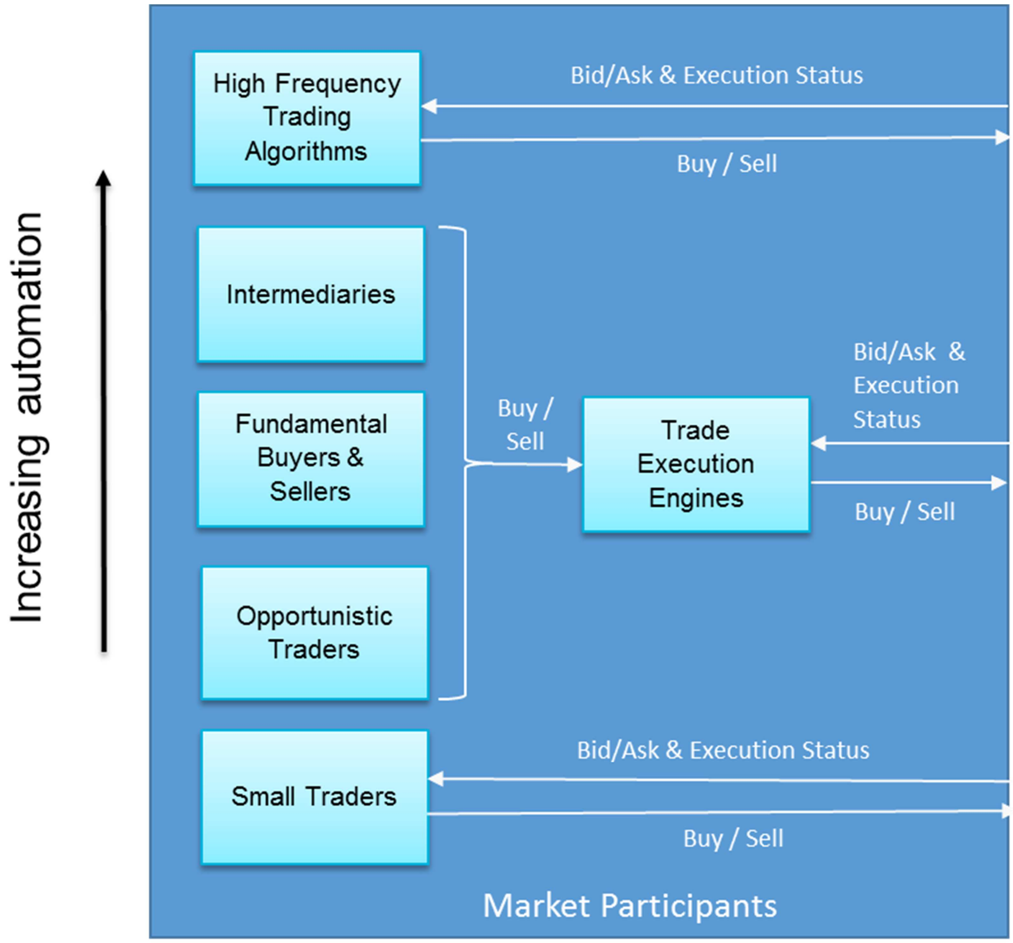

Figure 2: Market Participant Order Execution

2.2 Controlled process

The E-Mini market is modeled as a control process with two controllers (see Figure 3). The model contains an Execution Engine that is responsible for trade execution, an Order Book that maintains a set of buy / sell, price, quantity tuples represent pending orders, and a Circuit Breaker that halts trading when conditions are met.

The controlled process is the Execution Engine which executes trades of E-Mini futures contract(s) between a buyer and seller at specified price. The E-Mini Order Book process model captures the status of E-Mini buy and sell orders. The CME Globex Circuit Breaker process model monitors upcoming trades for excessive volatility.

The buyer and seller, contract quantity, and the trade price are supplied to the Execution Engine by the E-Mini Order Book controller. At the completion of the exchange the Execution Engine supplies trade data feedback to the E-Mini Order Book controller which updates the order book process model. The E-Mini Order Book controller also supplies the bid / ask data to the CME Globex Circuit Breaker controller which updates its process model. The CME Globex Circuit Breaker pauses executions of all transactions for 5 seconds, if the next transaction would execute outside the price range of 6 index points either up or down. During the 5-second pause, called the

"Reserve State," the market remains open and orders can be submitted, modified or cancelled, however, execution of pending orders are delayed until trading resumes.

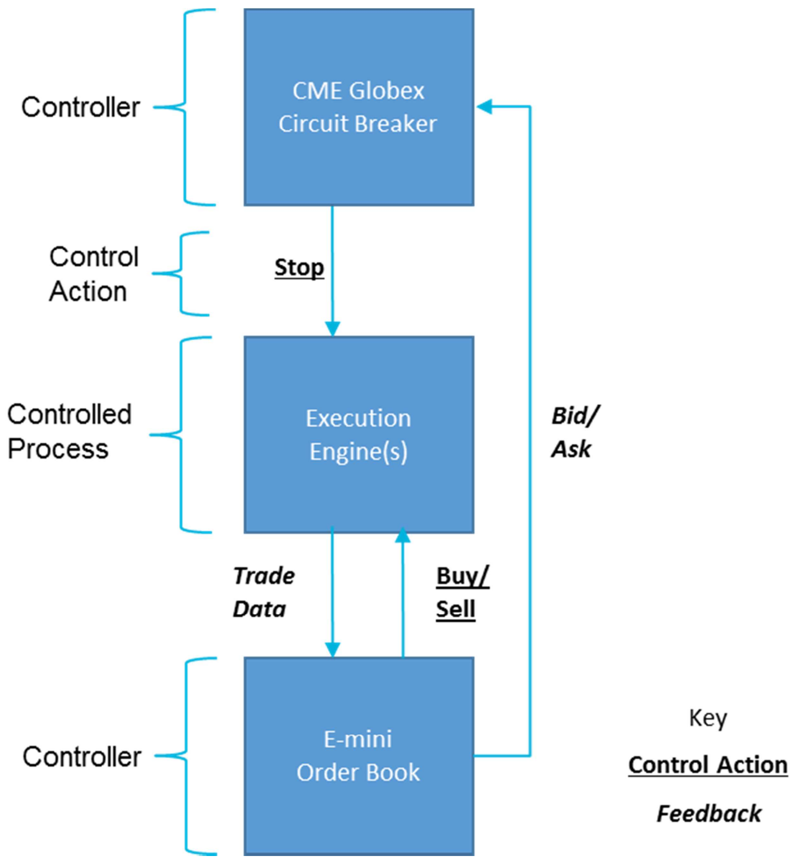

Figure 3: E-Mini Control Process

2.3 Participant / controlled process interaction

Market participants impact with the E-Mini controlled process by sending buy / sell orders to the E-Mini Order Book controller. Market participants receive bid / ask, order status, and market status information from the E-Mini controlled process (see Figure 4). The participant - control process interactions do not have any form of feedback control. That is, market participants can potentially destabilize the controlled process by sending it an unbalanced set of buy / sell orders.

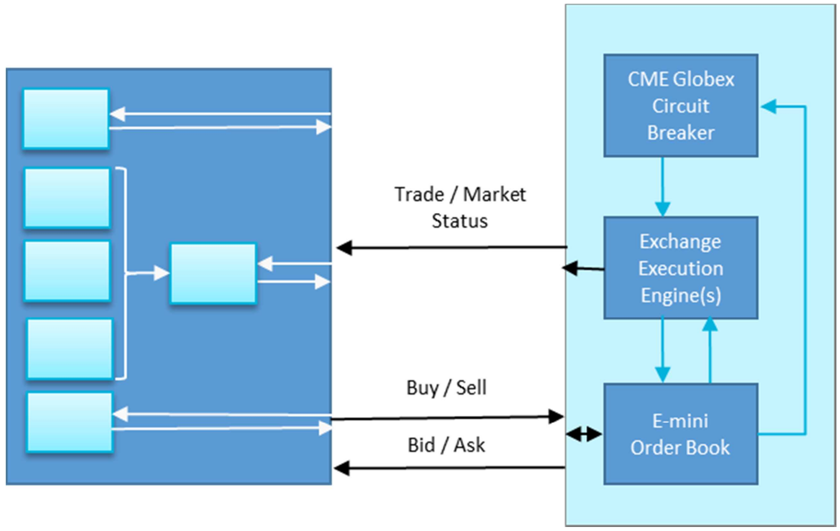

Figure 4: Participant Interaction with Controlled Process

3 Results

The STAMP accident investigation method was used to analyze constraints associated with the E-mini S&P trading market. STAMP defines control as *inadequate* if the any of the following occur:

1. Required control commands are not given
2. Unsafe control commands are given
3. Required commands are given too early or too late
4. Required control action stops too soon or is applied too long

The controlled process has an associated control action "Stop" that halts transactions for 5 seconds after which the control action is removed and trading resumes. The duration of the control action, 5 seconds, is determined by CME policy, not by the stability of the controlled process. That is: there is no feedback mechanism that prevents "#4 Required control action stops too soon" from occurring.

4 Conclusions

When the E-Mini electronic exchange market is modeled as a controlled process using the STAMP method, inadequate process control is revealed. As regulators balance market liquidity vs. stability it is important to consider the broad set of available systems engineering tools. STAMP is one example of those tools.

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