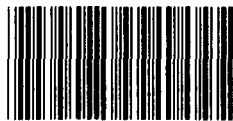May 1991

STOCK MARKET AUTOMATION

Exchanges Have Increased Systems' Capacities Since the 1987 Market Crash

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The Honorable Donald W. Riegle, Jr.
Chairman, Committee on Banking, Housing,
  and Urban Affairs
United States Senate

The Honorable John D. Dingell
Chairman, Committee on Energy and
  Commerce
House of Representatives

During the October 1987 market crash, stock markets' automated systems that facilitate order routing and trade execution experienced problems processing the unanticipated trading volumes. Problems occurred again in October 1989, when automated market systems were stressed during a period of volatile trading. This report is part of our continuing effort to assess the improvements made to stock markets' automated systems. It is addressed to you because of its relevance to your Securities and Exchange Commission (SEC) oversight responsibilities.

Our earlier reports focused on (1) actions taken by the New York Stock Exchange (NYSE) to improve its automated systems, and (2) steps that were needed for SEC to oversee stock markets' automated systems.[1] This report updates NYSE actions and describes the capacity improvements made to automated systems at the National Association of Securities Dealers (NASD), the American Stock Exchange (AMEX), the Midwest Stock Exchange (MSE), the Pacific Stock Exchange (PSE), and the Philadelphia Stock Exchange (PHLX). It also describes the markets' capacity planning efforts for their systems, including the extent to which they stress test the systems. In 1990, the six stock markets processed over 98 percent of stocks traded in the United States valued at $1.9 trillion. Details of our objectives, scope, and methodology are included in appendix I.

Results in Brief

All six stock markets have made improvements to increase the capacities of their automated systems. To ensure that their systems operate as planned, all six stock markets have conducted stress tests to simulate
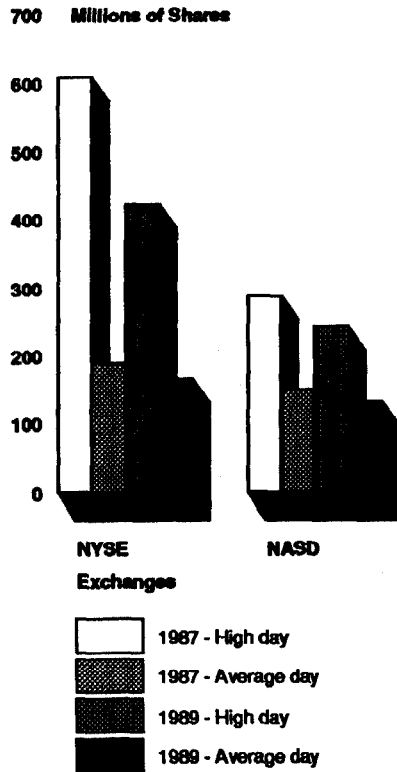
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[1]Financial Markets: Preliminary Observations on the October 1987 Crash (GAO/GGD-88-38, Jan. 26, 1988); Financial Markets: Status of Computer Improvements at the New York Stock Exchange (GAO/IMTEC-88-35, Apr. 27, 1988); and Financial Markets: Active Oversight of Market Automation by SEC and CFTC Needed (GAO/IMTEC-91-21, Apr. 2, 1991).

trading volumes higher than any previously experienced. The improvements made by the exchanges should better enable them to process daily trading volumes greater than those experienced in October 1987 and October 1989.
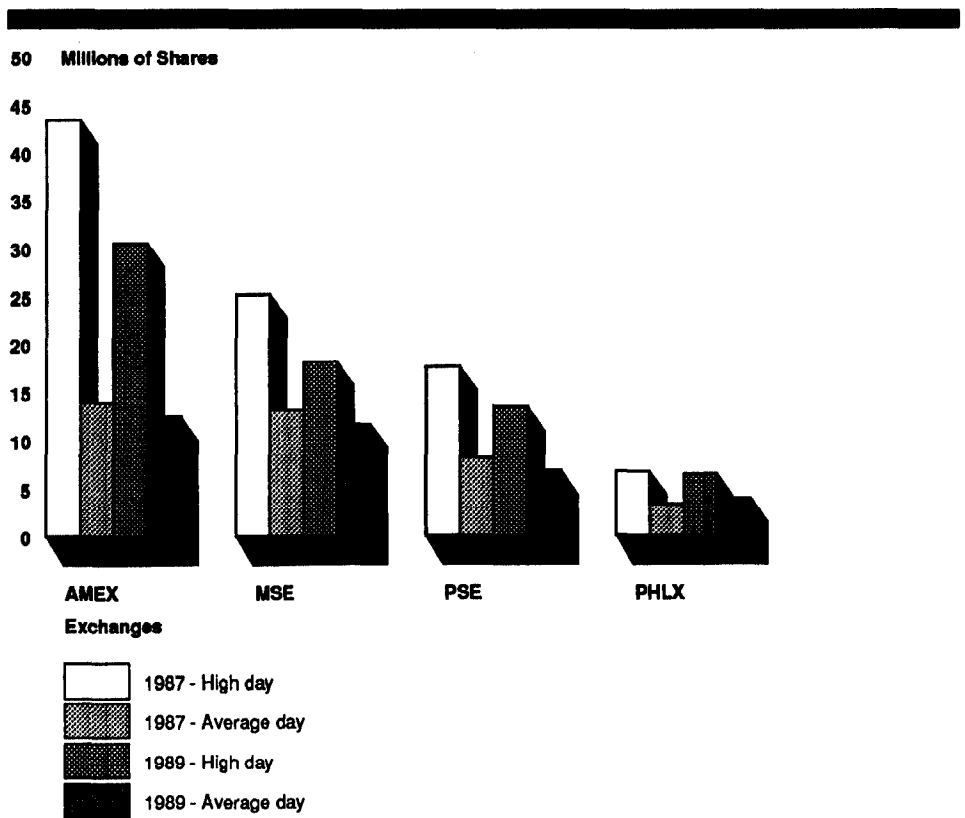
Background

High trading volumes experienced by U.S. stock markets in October 1987 and October 1989 stressed some of their automated systems. For example, on October 19 and 20, 1987, trading volumes exceeded NYSE automated systems' capacities. As a result, some orders were delayed or did not reach the trading floor for execution. In October 1987 and October 1989, NASD's system experienced delays executing orders. The NYSE encountered a minor software problem, which delayed the processing of some orders during the October 1989 volume surge. Figure 1 illustrates the high-volume days and average daily volumes in both years for NYSE and NASD, which together processed about 88 percent of the total trading volume in 1990.

Figure 1: Comparison of High and Average Trading Volumes for NYSE and NASD in 1987 and 1989

700 Millions of Shares

Legend:
- 1987 - High day
- 1987 - Average day
- 1989 - High day
- 1989 - Average day

Exchanges: NYSE, NASD

The other four stock markets experienced high trading volumes and problems in executing trades in October 1987 and October 1989. Figure 2 illustrates the high-volume days and average daily volumes in both years for these four stock markets.

Figure 2: Comparison of High and Average Trading Volumes for Four Other Stock Markets in 1987 and 1989

50   Millions of Shares

AMEX   MSE   PSE   PHLX

Exchanges

☐ 1987 - High day

▨ 1987 - Average day

▓ 1989 - High day

■ 1989 - Average day

Improvements Made by Markets to Process Higher Trading Volumes

Although there is always a risk that unanticipated volume surges can exceed the systems' increased capacity levels, all six stock markets have improved their automated systems to enable them to process daily trading levels greater than those experienced during the October 1987 crash. In this regard, three stock markets have improved their automated systems to process between 90 and 380 percent more volume than their systems could handle in October 1987. Another stock market's automated systems were enhanced to process between 20 and 40 percent more volume than their designed capacity in October 1987. The other two stock markets have also made improvements to increase the capacities of their systems since October 1987. However, we could not

determine the percentage increase, because they did not know their systems' capacities during the market crash. Tests conducted by all six stock markets indicate that their automated systems can process volumes ranging from 4 to 160 percent above their highest daily volumes ever processed. System improvements made by stock markets to process these high trading volumes include (1) installing more powerful computers, (2) adding electronic trade execution devices such as specialist display books,[2] and (3) enhancing communications capabilities. Details of these improvements are included in appendix II.

Stock Markets' Capacity Planning Processes

All six stock markets use capacity planning processes to estimate current and future systems capacity needs. Four of the six stock markets use statistical modeling to translate expectations of future trading volumes into automated systems capacity requirements. The factors used in these statistical models include daily trading volumes, ratios of automated system orders to nonsystem orders, program trading volumes, types of transactions (e.g., market and limit orders), numbers of orders entered into the system before the trading day begins, and number of shares per order. Stock markets use the results of their capacity planning processes to forecast when changes to their automated trading systems are needed, thereby avoiding overloading their computers and causing transaction processing delays and irregularities.

PSE, however, did not use a statistical modeling technique. Instead, it expects its system to have adequate capacity to process five times the average daily volume. A senior PSE official told us that a statistical modeling process is being used to forecast capacity requirements for a new automated system.

Officials of the sixth stock market, MSE, told us that they have a capacity planning process, but they would not tell us the factors used in this process because they consider them proprietary.

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[2]Electronic display books are terminals on the exchange floor which specialists use to execute trades. Specialists are responsible for making fair and orderly markets in their assigned stocks.

Stock Markets Stress Test Their Automated Systems

Testing systems to assess their ability to process data during periods of peak work load, commonly referred to as stress testing, helps identify and correct system weaknesses before they cause data processing disruptions in a live operating environment. All six stock markets have conducted stress tests of their automated systems at levels above historical peak trading volumes. The stress test results indicate that stock markets' automated systems can operate at volume levels above those experienced during the October 1987 stock market crash and the October 1989 volume surge without degradations in service. Three of these stock markets also obtained independent reviews of their test results.

NYSE has conducted six system stress tests since October 1987 and all were monitored by an independent consulting firm. We also observed these tests. The tests were conducted on nontrading days to simulate high trading volumes. Participants included exchange employees, member firms, and, at times, other stock markets. Systems tested included NYSE's automated order routing, execution, and reporting systems, the Intermarket Trading System,[3] and information dissemination systems such as the Consolidated Tape and Consolidated Quote systems.[4] The results of the most recent stress test of NYSE's automated systems, conducted in June 1990, indicate it can process a daily peak volume of 750 to 900 million shares without delays. These volumes are about 23 to 48 percent greater than the exchange's peak volume which was experienced on October 20, 1987.

NASD conducted separate stress tests on each of its major automated systems, using electronically simulated trading volumes. It has not conducted a systemwide stress test which would involve many market participants. NASD officials told us that they have not conducted a systemwide stress test because it would be extremely difficult and costly to perform on a nontrading day. They said that about 3,000 market participants would be needed to input the trade data needed to replicate a high-volume day. An independent consulting firm reviewed the results of several tests of major NASD trading systems and issued a report in June 1989. The report concluded that NASD's trading systems could process about a 300-million-share day without degradation if NASD

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[3]The Intermarket Trading System is an electronic trading linkage among the primary and regional stock exchanges and NASD. The system allows brokers to seek the best execution price in any market within the network.

[4]The Consolidated Tape System receives and disseminates last-sale prices in listed stocks in all markets in which they are traded. The Consolidated Quote System collects and disseminates current bid and asking quotations from and to all market centers in which listed stocks are traded.

increased the capacity of the communications link between two critical computer networks. This volume level represents about 4 percent above the volume processed during the market crash. A senior NASD official told us that the association believes the assumptions used by the consultant were too conservative and NASD's automated system could process up to 350 million shares daily without degradation. Another senior NASD official told us that recent improvements have increased the system's capacity so that it can process up to 450 million shares daily. An independent consulting firm is reviewing the system's ability to process this daily share volume.

NASD conducted other stress tests on the evening after the October 16, 1989, market surge. These tests were performed to determine if the capacity upgrade to its communications link between the system that delivers quotation update information and the Small Order Execution System could have avoided the problems experienced during the morning of October 16, 1989. Stress test results indicated that the capacity of the communications link had more than doubled; if this enhancement had been made before October 16, 1989, the problem would not have occurred. A senior NASD official told us that changes to increase the communications links' capacity were being made at the time of the October 1989 market surge, but were not complete.

PSE conducted three stress tests in March 1988 of its automated system. Member firms were used to send orders to PSE for execution. The test results were attested to by an independent consulting firm and indicate that PSE could process about 8 percent more than the peak daily volume experienced on October 19, 1987. However, PSE's automated system experienced processing delays during a 1-hour volume surge on October 13, 1989. A senior PSE official told us that its automated trading system is still subject to delays during high-volume periods and there are plans to replace it by the end of 1991.

The three other stock markets have stress tested their automated systems with volume levels exceeding those experienced in October 1987 and October 1989. AMEX stress tested components of its automated trading system during the third quarter of 1989 and the first quarter of 1990. MSE conducts periodic stress tests when major changes are made to its automated systems. For example, MSE tested its automated system in April 1990 when it installed new computers. Since October 1989, PHLX has periodically stress tested its system at various simulated trading volume levels, including the share volumes that it expects to process during an industrywide, 600-million-share trading day. The results of

these three exchanges' tests have not been independently reviewed by external organizations. Officials of these stock markets believe that obtaining such external reviews is not cost effective.
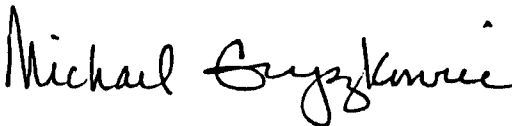
Conclusion

The New York, American, Midwest, Pacific, and Philadelphia Stock Exchanges, and the National Association of Securities Dealers have all made improvements to increase the capacities of their automated systems used to facilitate order routing and trade execution. We believe these improvements should better enable the six markets to process daily trading volumes, such as those experienced during the October 1987 market crash and the volume surge of October 1989.

We discussed the information contained in this report with officials from the six stock markets and SEC, who agreed with the accuracy of the information provided. We have incorporated their comments in the report where appropriate.

We are providing copies of this report to the Chairman of the Securities and Exchange Commission, and to other interested members of the Congress and the public. We will also make copies available to others upon request.

Should you have any questions about this report or require additional information, please contact me at (202) 275-3455. Major contributors to this report are listed in appendix III.

Howard G. Rhile
Director, General Government
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Objectives, Scope, and Methodology

Our objectives were to (1) document capacity improvements made to stock markets' automated order routing and execution systems since the October 1987 stock market crash, and (2) review stock markets' capacity planning efforts, including the extent to which they stress test their systems.

Our review was conducted at the SEC, New York Stock Exchange (NYSE), National Association of Securities Dealers (NASD), American Stock Exchange (AMEX), Midwest Stock Exchange (MSE), Pacific Stock Exchange (PSE), and the Philadelphia Stock Exchange (PHLX). These stock markets were selected because they processed over 98 percent of the total equities trading volume for all U.S. stock markets in calendar year 1990, and all experienced problems with their automated systems during the October 1987 stock market crash. In addition, these stock markets experienced problems with their automated systems during the October 1989 volume surge.

Our review was limited to the automated systems that support equities order routing and execution at the six stock markets. We did not review the nonautomated methods these stock markets use to process trades or the automated systems that support posttrading, settlement, or clearance functions.

We reviewed SEC's report on the October 1987 market crash to document the problems experienced by stock markets' automated trading systems. We used our previous reports that highlighted system problems at the New York Stock Exchange to determine the status of improvements since that time.[1] We also analyzed correspondence stock markets sent to SEC that documented system problems experienced and corrective actions taken as a result of the high trading volumes experienced in October 1987 and October 1989.

We toured stock markets' trading floors to observe improvements such as additional electronic display books and improved printers and terminals. We interviewed senior stock market and data processing officials and reviewed (1) documentation of changes and improvements made to automated order routing and execution systems since October 1987, (2) capacity plans and other documents to determine the factors stock markets used to estimate future system needs, and (3) stress-test plans and results. We also attended system stress tests conducted by the New York Stock Exchange.

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[1]GAO/GGD-88-38, Jan. 26, 1988 and GAO/IMTEC-88-35, Apr. 27, 1988.

We conducted our review in accordance with generally accepted government auditing standards, between March 1990 and January 1991.

Systems Improvements Enhance Stock Markets' Processing Capabilities

Since the October 1987 market crash, all stock markets we visited have made enhancements to their automated systems used to facilitate order routing and trade execution. These enhancements were implemented to improve the stock markets' abilities to process high trading volumes. In our previous reports we discussed the problems experienced by NYSE's automated systems in October 1987 and the status of corrective actions. This appendix discusses additional steps taken by NYSE since those reports were issued. It also discusses problems encountered in October 1987 and October 1989 by five other stock markets' systems, and the actions taken to correct these problems. Except for a minor software problem, NYSE systems did not encounter processing problems in October 1989.

New York Stock Exchange

NYSE has continued to make changes to its automated systems to improve trade processing:

- NYSE has increased the number of electronic display books from 361 on March 31, 1988, to 525 as of October 31, 1990. This has increased the amount of order traffic displayed electronically from 78 percent in March 1988 to about 93 percent. All of the Standard & Poor's 500 stocks that are traded on the NYSE and 99 percent of Intermarket Trading System stocks are displayed electronically. These changes were made to improve the efficiency of order processing by reducing the reliance on printers used to process orders.
- The exchange also enhanced the Intermarket Trading System in January 1990, by allowing intermarket trading commitments to enter directly into specialists' display books rather than through printers at the specialists' trading posts. During the October 1987 crash these printers could not process the avalanche of orders fast enough and many orders could not be executed within the 2-minute time limit. This enhancement is designed to allow specialists to execute Intermarket Trading System orders in a more timely manner.
- NYSE has enhanced its order routing system configuration to allow for more efficient processing of market, limit, and odd-lot orders. The new SuperDOT system operates on more powerful computers that provide about 40-percent more processing capacity than NYSE's old systems.
- In addition, NYSE installed a message flow-control mechanism in December 1989 that can slow the rate of orders that enter the exchange's automated systems. Message flow-control was designed to maintain manageable order traffic rates into NYSE's automated systems during volume surges, even when demand exceeds the systems' capacities. Senior exchange officials told us that flow-control was developed to

protect the small investor by allowing continued access to the automated trading systems during high-volume periods. Exchange policy calls for message flow-control to be implemented first on program trading lines during high-volume periods and on nonprogram trading lines only as a last resort. NYSE has not had to invoke flow-control to date.

National Association of Securities Dealers

In October 1987, NASD experienced delays in executing orders of up to 1,000 shares. The automated Small Order Execution System, used to execute such orders, rejected a large number of orders because it was designed to prohibit order execution for securities that were in locked or crossed markets.[1] Rejected orders had to be executed manually, which slowed order execution. Market makers, wishing to execute orders during locked or crossed markets, also experienced difficulty contacting each other by telephone. In the confusion and uncertainty of these conditions, some market makers withdrew from participation in the system. NASD took several actions to respond to the problems. These actions included

- implementing a software change to the Small Order Execution System in June 1988 that permits the execution of orders for securities in locked or crossed markets at the best available price;
- enacting a rule change in June 1988 that prohibits market makers from using the execution system for 20 trading days if they choose to withdraw from the system; and
- installing the Order Confirmation Transaction System in 1988, allowing subscribers to direct their orders to other market makers through computer terminals as an alternative to the telephone.

In October 1989, the surge in trading volume coupled with market makers' attempts to unlock and uncross their markets to avoid penalties, resulted in communication delays of about thirty minutes between the Small Order Execution System and NASD's main computer system. Because of these delays, orders were executed on the basis of inaccurate information. In 1990, NASD made several changes to its systems to improve trade processing during high-volume periods. Changes included enhancing its computer communications capability and installing a new

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[1]A locked market exists when the bid price quoted by a market maker in a security equals the ask price quoted by another market maker in the same security. A crossed market is created when the bid price quoted by one market maker in a security is greater than the ask price quoted by another market maker in the same security.

computer that increased the Small Order Execution System's execution rates by 40 percent.

American Stock Exchange

AMEX experienced high trading volumes that affected its ability to execute some orders in a timely manner during the October 1987 market crash. At the time of the crash, specialists used automated touch screens to execute market orders of 1,000 shares or fewer. The screens allow up to six orders to be displayed for execution through the exchange's automated order execution and reporting system. When order volume exceeded the touch screens' capacity of six orders, new orders were automatically printed out on hard copy. However, printed orders were not displayed on screens. Thus, specialists had to compare orders on the touch screens and the hard copy printouts to ensure that orders were executed in the proper sequence. To reduce the chance of executing orders out of sequence, many AMEX specialists shut off their touch screens and manually executed orders from hard copy printouts. AMEX believes that its automated and manual systems worked well during the market crash and did not take steps to address the order storage capacity of the touch screens. However, AMEX plans to increase the capacity of the touch screens by the end of 1992. Until then, if the capacity of the screens is reached, specialists will turn off their screens and all orders will be routed through their printers to maintain an accurate sequencing of orders.

On October 16, 1989, AMEX experienced problems with its system that controls order printers on the trading floor. These problems, combined with the high order volume, led to a backlog of messages within the exchange's order execution and reporting system. The backlog reached a point where the system could no longer store incoming or outgoing messages and some orders were not executed in a timely manner.

To correct these problems, AMEX has (1) enhanced the printer network's capacity to store messages, thereby reducing the possibility of orders being delayed, and (2) modified its printer network to redirect orders from backlogged printers to other printers to avoid delaying order execution.

Midwest Stock Exchange

During the week of October 19, 1987, MSE received approximately three times the number of transactions of an average week. On October 19 through October 21, the high volumes exceeded system capacities and resulted in orders executed at prices that were significantly different

than the market price at the time the order was received. In addition, the capacity of MSE automated files that maintain records of executed trades was exceeded. To address these capacity problems, MSE has added more powerful computers, data communications circuits, and new software.

On October 13, 1989, the exchange's automated order routing and execution system experienced order processing delays. By the next trading day, the exchange modified the system's software and transactions were executed without delays.

Pacific Stock Exchange

During the October 1987 market crash, PSE's automated order routing and execution system lost orders because its front end communications processors did not have adequate capacity to handle the unprecedented trading volumes. PSE took several actions to address this problem, such as

- increasing the communication capacity between its San Francisco and Los Angeles trading floors in December 1987 by approximately 50 percent; and
- adding a communications processor in 1988 to reduce system work load and increase order processing capacity.

During the volume surge on October 16, 1989, a PSE communications processor again lost messages. During the trading day, PSE officials detected this problem and made necessary modifications. In addition, PSE's automated order routing and execution system's ability to execute trades and provide timely trade data was impaired. At one point, trade data were one hour late. As a result, specialists could not properly decide how to execute orders.

A senior PSE official indicated that the communications processors were and continue to be the major weakness within the exchange's automated system because they are outdated, difficult to maintain, and subject to backlogs during high-volume periods. To improve its operations, PSE is developing a new automated trading system. This system should become operational by the third quarter of 1991 and is expected to double the exchange's order processing capability and eliminate dependence on the old communications processors.

Philadelphia Stock Exchange

During the October 1987 stock market crash, the exchange's automated systems became backlogged. These backlogs delayed by more than one hour the pricing, executing, and reporting of orders. To reduce specialists' risks of taking larger stock positions on the basis of inaccurate price information, exchange officials decided to slow down trading by disengaging the automated system and switching to manual order execution. This action resulted in delayed reporting of order executions to member firms. In addition, PHLX officials requested member firms to reroute orders to other markets to reduce system work load. PHLX implemented several system changes to address the problems. These changes included

- installing a computer control command, on October 26, 1987, to allow the exchange to switch to manual order execution while continuing to deliver system-generated execution reports to member firms; and
- increasing the capacities of its order routing and execution system and its quotation and transaction processing system through software modifications and additional computer hardware.

During the October 1989 volume surge, the exchange's order routing and execution system experienced delays in executing orders. To address this problem, PHLX redesigned and increased the capacity of its automated order routing and trade execution system.

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