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A Taxonomy of Automated Trade Execution Systems

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Abstract

A taxonomy of existing and planned automated trade execution systems in financial markets is provided. Over 50 automated market structures in 16 countries are analyzed. The classification scheme is organized around the principle that such markets consist of an algorithm that performs a trade matching function, together with information display and transmission mechanisms. Automated market structures are classified by ordered sets of trade execution priority rules, trade matching protocols and associated degree of automation of price discovery, and transparency, to include informational asymmetries between classes of market participants. Systematic differences in systems across types of financial instruments, geographical market centers, and over time are analyzed.

JEL Classification Numbers:
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Contents

Summary

Computerized trade execution is the final step in the automation of financial trading market operations, whereby traders submit orders through computer terminals, and the host computer determines trades, reporting results back to traders through their terminals. Over fifty automated trade execution systems currently operate worldwide, and at least five international organizations are looking into the regulation and standardization of the trade execution process.

This paper provides unified technical summary of 53 automated trade execution systems, which are differentiated with respect to geographical location, date of inception, type of securities traded, and extent of global reach and are then described in terms of three classifications.

First, automated systems are classified by an ordered set of trade execution priority rules, eleven of which are identified. The priority assigned to bids and offers for a security governs the place of the order in the queue awaiting execution, and determines the distributional properties of transaction prices, conditional on order flow. A comprehensive view of the nature of automated systems in sixteen countries is provided, by security type and over time.

Second, automated systems are classified according to the degree of automation of the price discovery process in order to clarify the diversity of trade-matching algorithms observed in existing automated markets. The level of price discovery has implications for the type and degree of regulatory oversight of automated markets. Trends in the automation of the price discovery process by security type, market center, and over time are analyzed. It is found not only that the number of automated markets is growing over time, but also that the degree of automation of market structure within this class is increasing.

Third, systems are classified by information structure. Regulatory concerns are focused on the type and amount of information provided to different classes of investors and system participants. Informational differences influence price volatility and liquidity of the market. All systems are classified with respect to the types of information they offer to direct system participants. Asymmetries of information between traders working on the system and outside investors, who do not have direct access to the automated market, are explored for a smaller set of markets. The paper examines differences in the provision of information by type of security, differentiating between futures and options trading and stock trading according to the degree to which participants have access to electronic order books.

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I. Introduction

Automation of a market can include computerization of information dissemination services, order routing, and clearance and settlement procedures. This paper is concerned with a different form of automation, that of the technology of trade execution: computerization of the trade matching, quantity allocation, and in most cases, price discovery mechanisms. The study of automated trade execution systems is a study in the design of automated auctions. Any system is basically a communications technology for passing messages between traders, combined with a set of rules for trade execution that have an impact on trading strategy and pricing outcomes. The latter are embodied in the trade matching algorithm. The former are manifested in the type of information displayed to system participants and in the types of bids, offers, and personal identifiers allowed by the system design.

The theoretical and experimental literature on auctions, as well as work on the theory of financial market microstructure, indicates that the precise form of the trading institution matters a great deal in the analysis of agent behavior, the properties of transactions prices, and welfare. 1/ Despite the extensive proliferation of automated trading markets, little is known about their structure. Yet, a substantial amount of transactions data from such systems soon will become part of the data banks upon which both theoretical observations and empirical work is based.

The purpose of this paper is to provide a taxonomy of existing and planned automated trade execution and auction mechanisms in financial markets. 2/ The classification system is organized around the principle that automated trade execution systems are computerized mathematical algorithms that enable trade matching, combined with information display and transmission mechanisms. This classification is in three parts, although it will be clear that the divisions are not independent when examining any particular market.

The first classification concerns priority of trade execution. The priority assigned to bids and offers, conditional on the state of the system at any given time, governs the place of the order in the queue awaiting execution. The distribution of bids and offers in the queue determines the

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1/ See, for example, the survey by Friedman (1992).

2/ In particular, this paper is based on data for specific systems in practice, and is not a general normative discussion of possible system design. Proposals in the academic literature for elements of automated execution mechanism design date from the work of Black (1971), and include Peake, Mendelson, and Williams (1979), Amihud and Mendelson (1985), Cohen and Schwartz (1989), and Harris (1990).

distributional properties of transactions prices, given the order placement strategies of traders. 1/

The next classification scheme is by the degree of automation of the price discovery process. Automated trading systems exist which do not determine transactions prices endogenously within the system. On the other end of the spectrum, it is possible and planned to automate the pricing of certain securities requiring a variety of pricing inputs to the extent that only one such input is priced based on the trade matching algorithm and order flow, while the remainder are calculated by formula. The extent of automation of price discovery helps determine the amount of economic interest in any given automated market structure. This scheme is structured to clarify the diversity of matching algorithms observed in existing automated markets.

The final classification is by information structure and transparency. Transparency is the extent to which trading information is made available after each discrete market event. The degree of transparency in a system influences variables such as price volatility and liquidity of the market. 2/ Regulatory concerns are focused on the types and amount of information provided to investors who are not direct system participants, as well as on information provided to traders and to themselves. The levels of transparency described in this paper relate directly to information displayed to various classes of system users and offer data on asymmetric information issues stemming from market design.

Any taxonomy is in the mind of the particular individual designing the scheme, and other ways of classifying automated trade execution systems may be possible. The divisions selected here are important with respect to considerations of pricing and market efficiency. The particular taxonomy suggested also is not devoid of policy interest or motivation, especially with respect to regulatory issues. The United States General Accounting Office (GAO) has stressed the need for system information and technical reviews of automated markets that ensure that automated trade execution systems do not diminish an exchange's competitiveness and pricing efficiency (GAO, 1989). The Commodity Futures Trading Commission (CFTC) is required to judge new market mechanisms with respect to the openness and competitiveness of open outcry auction on a trading floor, based on CFTC Regulation 1.38. The public interest requirement of the 1974 Commodity Exchange Act even defines the public interest in terms of reliable price discovery. Similar concerns appear in the Security and Exchange Commission's (SEC) approach to

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1/ See Domowitz and Wang (1992) for an analysis of the stationary distribution of transactions prices in a simple automated system for continuous trading. It is shown, for example, that the distribution of prices differs greatly from that derived by Mendelson (1982) for the case of clearing house auctions.

2/ See, for example, Madhaven (1992).

the regulation of automated markets. 1/ All three divisions of the classification scheme are oriented to provide a basis for any such evaluations.

On an international scale, the International Organization of Securities Commissions (IOSCO) currently is in the process of investigating regulatory issues surrounding the growth of automated systems world-wide. A review of automated execution algorithms is explicitly suggested for all regulatory jurisdictions in the IOSCO statement of principles for the oversight of screen-based trading systems (IOSCO, 1990). The form of the matching algorithm, including its priority rules, is held to have implications with respect to regulatory jurisdiction across countries, as well as for the degree of regulatory oversight required. 2/ One of the ten principles focuses explicitly on system transparency. Further concerns over transparency in automated trade execution mechanisms recently have been enunciated by the SEC. 3/

The remainder of the paper begins in section II with an overview of the extent of automated trade execution in financial markets. Over 50 systems are listed, spanning financial centers in 16 countries. 4/ There is an additional taxonomy inherent in the presentation, with respect to geographical location, date of inception, and the extent of global reach for any system documented. Systems also are differentiated with respect to the type of securities traded, as well as with respect to their ownership.

Section III contains the classification by trade execution priority rules. Eleven different rules in existence are isolated, and it is argued that all systems can be described by an ordered set of these priorities. The classification is applied to all systems listed in section II, providing a comprehensive view of the nature of systems on a global basis, by security type, and over time.

The classification in terms of the degree of automation of price discovery is presented in section IV. Seven levels of such automation are described, and all systems are classified by a set of these levels. Each such degree of price discovery automation is linked to particular forms of

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1/ See, for example, Ruder and Adkins (1990), and the references in Domowitz (1990a).

2/ See also Corcoran and Lawton (1991). Participants in the working group drafting the IOSCO statements included the United States, Australia, France, Italy, Japan, Switzerland, the United Kingdom, and West Germany.

3/ See letter from Brandon Becker, Deputy Director, SEC, to Shokichi Takagi, Director, Secondary Market Division, Ministry of Finance, Japan, dated 29 July, 1991.

4/ The list is as complete as possible, but some systems known to exist are excluded for lack of enough information. These include the Belgian, Austrian, and Barcelona exchanges, in particular. It also is possible that additional proprietary systems exist, but are unknown to the author.

trade matching algorithms. Trends in the automation of price discovery by security type, market center, and over time are analyzed.

Information structure is the topic of section V. A comprehensive set of data provided to users of existing systems is given. Systems are classified first with respect to information provided to traders directly participating in system trading. Differences in information provision by type of security receive special attention, with futures and options trading differentiated from stock trading by the degree to which participants have access to order books. Anonymity with respect to quotes also is investigated. Some examples of screen design are offered. Systems then are classified by the type of information transmitted to investors outside the system, who participate only indirectly through the transmission of orders to system traders. A view of the asymmetric information structure between traders and outside investors is thereby provided.

A bibliographical note is in order here. Detailed information on automated trade execution systems is not widely available. The data presented in this paper are gathered from diverse sources, including regulatory documents and letters, surveys by the International Organization of Securities Commissions, and many exchanges. Citations for each individual fact would be unwieldy, at best. A list of such references is available upon request.

II. The Extent of Automated Trade Execution

Automation of the trade execution process in financial markets is taking place on a large scale. Trading floors, where they exist, are being superseded or complemented by automated trade execution systems on a worldwide basis. The institutions of open outcry floor trading and telephone dealer markets are consistently abandoned in favor of automated trade execution in the construction of new markets for both day and off-hours trading activity. Considerations of cost, market efficiency, and competition between exchanges for order flow, abetted by the advances in off-exchange trading, all have contributed to this growth in the utilization of technology.

Tables 1 through 3 contain a listing of over 50 automated trade execution systems in use or planned over the next couple of years; full names of systems and their associated exchanges are given with their acronyms in the appendix. Tables 1 and 2 contain information on futures/options systems and stock/bond systems, respectively, operating as a formal exchange. This means that the market is regulated as an exchange in its domestic market, and definitions for such treatment vary from country to

Table 1. Automated Futures and Options Exchanges

System (Exchange)	Date	Hours	Members (Terminals)	Number of Securities/ Products	Global (Country)
GLOBEX (CME)	1992	Night	(250)	100 (potential)	Yes (USA)
ATS/2 (IFOX)	1989	Day	N/A	4	No (Ireland)
FAST (LFOX)	1990	Day	N/A	4	Yes (UK)
APT (LIFFE)	1989	Night	N/A	1	No (UK)
ATS (NZFOE)	1985	Night	37	11	No (New Zealand)
SYCOM (SFE)	1989	Night	20 (30)	5	No (Australia)
FACTS (TIFFE)	1989	Day	262	4	No (Japan)
AUTOM (PHLX)	1990	Day	N/A	37	No (USA)
DTB (GFOE)	1990	Day	69	19	Planned (Germany)
S-MART (MEFF)	1990	Day	37 (135)	2	No (Spain)
MOFEX (MOFF)	1990	Day	48 (43)	2	No (Spain)
SOFFEX (SOFFE)	1988	Day	48 (800)	14	No (Switzerland)
CORES-F (TSE)	1988	Day	132 (213)	1	No (Japan)
CORES-O (TSE)	1989	Day	132 (274)	1	No (Japan)
SFTS (OSE)	1988	Day	108 (190)	2	No (Japan)
OTS (OSE)	1989	Day	108 (225)	1	No (Japan)
TGE (TGE)	1988	Day	N/A	6	No (Japan)
RAES (CBOE)	1985	Day	N/A	180	No (USA)
AUTO-EX (AMEX)	1985	Day	N/A	All equity options	No (USA)
POETS (PSE)	1991	Day	N/A	Listed equity options	No (USA)
SOM (SOM)	1985	Day	N/A (50)	13	Yes (Sweden)

Table 2. Automated Stock and Bond Exchanges

System (Exchange)	Date	Hours	Members (Terminals)	Securities	Global (Country)
SEATS (ASX)	1987	Day	90 (600)	All ASX listed stocks	No (Australia)
CAC (Paris)	1986	Day	45	All stocks Most bonds	No (France)
IBIS (FSE)	1991	Day	70 (25)	30 stocks 29 bonds	No (Germany)
GTB (Milan)	1991	Day	N/A	Most stocks (phased in)	No (Italy)
MORRE (MF)	1990	Day	20	All stocks	No (Quebec)
SIB (SSE) 1/	1991	Day	54 (319)	116 stocks	No (Spain)
SAEF (LSE)	1989	Day	N/A	LSE listed stocks	No (UK)
BEACON (BSE)	1987	Day	N/A	Stocks traded over ITS	Yes (USA)
NSTS (CSE)	1985	Day	(54)	425 stocks (2,700 capability)	No (USA)
MAX (MSE)	1981	Day	N/A	Exchange listed stocks	No (USA)
ABS (NYSE)	1976	Day	53 (231)	Bonds	No (USA)
OHT (NYSE)	1991	Night	N/A	NYSE stocks	No (USA)
SCOREX (PSE)	1969	Day	N/A	Listed stocks	No (USA)
PACE (PHLX)	1976	Day	N/A	Listed stocks	No (USA)
SOES (NASD)	1985	Day	N/A (2,405)	NASDAQ stocks	No (USA)
CORES (TSE)	1982	Day	124 (375)	1,612 TSE stocks	No (Japan)
STS (OSE)	1991	Day	78 (305)	1,009 OSE stocks	No (Japan)
CLOB (SSE)	1987	Day	N/A	SSE, HK listed stocks	No (Singapore)
CATS (TSE)	1977	Day	75 (300)	850 TSE stocks	No (Canada)
HKTS (SEHK)	1993	Day	N/A	SEHK listed stocks	No (Hong Kong)
ELECTRA (CSE)	1987	Day	N/A 2/	2,000 bonds 275 stocks	No (Denmark)
MATCHMAKER (VSE)	1988	Day	N/A (200+)	1,500 stocks	No (Canada)
MAX-OTC (MSE)	1987	Day	N/A	OTC stocks	No (USA)
SAX (SSM)	1989	Day	N/A (300)	Listed stocks, bonds	No (Sweden)
OLS (NYSE)	1986	Day	N/A	Odd lots for NYSE listed stocks	No (USA)

1/ Spanish stock exchanges: Madrid, Barcelona, Bilbao, Valencia.
2/ All brokers are allowed terminal-to-host hookups.

Table 3. Proprietary Automated Trading Systems

System (Exchange)	Date	Terminals	Securities	Global (Country)
INSTINET (REUTERS)	1985	N/A	Stocks Bonds	Yes (UK)
BEST (KB)	1986	30	100 + UK stocks	No (UK)
TRADE (BZW)	1986	N/A	100 + UK stocks	No (UK)
NORDEX (TRANSVIK)	1990	20 Firms	Scandinavian stocks	Yes (UK)
WAS (WASI)	1991	23	Stocks Bonds	No (US)
POSIT (JEFCO)	1987	N/A	Stock Portfolios	No (US)
DELTA (RMJ)	1988	N/A	Options on treasures	No (US)

country. 1/ Table 3 covers proprietary systems, which enable the trading of stocks for the most part, but includes one options system. 2/ Proprietary systems are not registered as exchanges, although they are subject to many of the same trade reporting requirements. Automated systems are included in these lists only if the trading protocol explicitly excludes person to person interaction for the purpose of trade execution. There is a variety of proprietary off-exchange systems, in particular, that act mainly as electronic bulletin boards, requiring that trades actually be consummated by telephone. 3/

Most of these efforts are very new. Over 25 systems have been installed between 1988 and 1991, with several more scheduled to start operation between 1991 and 1993. The vast majority of systems date from 1985 or later. Recent growth is more pronounced in the futures and options area. Roughly 81 percent of automated futures/options exchanges have come on line since 1988, compared to 40 percent of total stock exchanges. This fact is partially explained by the growth in the trading of futures and options on a global basis. The number of financial futures and options listed on exchanges has grown from 16 in 1978 to 205 in 1988, for example, and the number of futures and options exchanges has grown accordingly. 4/ As such growth stabilized, the number of automated futures/options exchanges introduced since 1990 (6) parallels new automated stock and bond systems (7), both representing about 28 percent of the total.

Automated markets are classified with respect to the system sponsor (exchange or company), date of inception, location, and global reach. A total of 16 countries are represented. Hours of operation vary widely, and may even differ with respect to individual products traded on a given system. The main distinction is between systems which operate during the regular trading day and those that operate after-hours, usually

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1/ In the United States, for example, an exchange is defined within the context of the Securities Exchange Act under Section 3(a)(1). The definition is so broad that virtually anything could be considered an exchange. Regulatory history has shown, however, that merely having a communication technology for bringing together buyers and sellers is necessary, but not sufficient, for a securities market to be classified as an exchange.

2/ Delta Government Options ("Delta") is operated by RMJ Securities, a registered clearing agency, and RMJ Options, a registered broker-dealer. The system trades options on underlying United States Treasury bills, bonds, and notes. Participants are primarily large banks and securities firms.

3/ Twenty systems have been granted the right to operate as non-exchange facilities in the United States, for example. Several of these operate as such electronic bulletin boards. Others have failed by the time of the writing of this paper, including Econ Investment Software, Adler & Co., Security Pacific, Troster Singer, Exchange Services, Transaction Services, and B&K Securities. See Becker, Adkins, Fuller, and Angstadt (1991).

4/ See Chapman (1990), tables 6 and 7.

supplementing a conventional trading floor. Examples of the latter include APT, GLOBEX and SYCOM for futures, and OHT for stocks.

The vast majority of automated systems operate during regular trading hours. In many cases, the automated system is the main trading system of the exchange, i.e., all trades in a financial product are processed through the automated execution mechanism. Exceptions generally involve systems which are designed to handle only small retail customer orders. Such mechanisms use prices for trade matching based on activity in a floor trading market that usually is in operation during the same time period. These limited execution mechanisms are relatively rare in futures and options trading, including RAES, AUTOEX, AUTOM, and POETS. Examples in the case of the trading of stocks and bonds are BEACON, MORRE, PACE, SCOREX, and SOES. Most execution systems of this type are quite old, dating back as far as 1969. The newer generation of automated mechanisms is composed of systems that endogenize the price discovery process.

Global reach pertains to whether or not terminals are located outside the home country. In most instances, a "no" in the last column of the tables implies that there are regulatory restrictions against such an operation, but that is not always the case. The IBIS stock trading system is under no such legal restriction, for example, but all terminals are located in Germany with no immediate plans for expansion into cross-border trading.

Computerized exchanges easily lend themselves to the idea of cross-border trading. There are no real technological barriers. Despite the frequency with which one reads about "globalization of trading," however, electronic markets are not spearheading the move into international trading activity at present. Only 19 percent of futures/options systems are oriented this way, with the DTB system planning such operations. The FAST system of the London Futures and Options Exchange specifically advertises its international trading operations as a direct way to increase the number of market participants and attract liquidity. The GLOBEX system of the Chicago Mercantile Exchange will operate in partnership with foreign exchanges and offer overseas terminals. Although there is a small sample problem here, it appears that the movement towards building systems with some global reach is growing, with 29 percent of exchanges built after 1989 exhibiting cross-border capabilities. In stock trading, only BEACON of the Boston Stock Exchange maintains a foreign connection, and it is limited to a link with Montreal. The best global reach is provided by INSTINET, which has terminals located around the world. Trading in U.S. equities is supplemented by dealing in U.K., French, German, Dutch, Swiss, Norwegian, Finnish, and Swedish stocks. Many of the problems arising with respect to greater cross-border trading activity through automated exchanges concern regulatory issues and international regulatory cooperation.

III. Classification by Ordered Sets of Priority Rules

The trade execution function is an algorithm that performs order matching according to a set of rules governing the priority of submitted bids and offers. The priority rules determine the place of a bid or offer in the queue awaiting execution. A match occurs under several circumstances, depending on the design of the system. In some systems, a match occurs the moment an order rises to the top of the queue, at a price possibly determined outside of the automated system. A match may occur in other designs when a bid or offer at the top of the queue is accepted directly by the touch of a button. In limit order matching systems, transactions occur when the orders cross; i.e., when the price of the best offer to buy is equal to or greater than that of the best offer to sell. This section is devoted to the priority rules; trade matching and price discovery is deferred to section IV.

An example of a specific trade execution algorithm may help. The following subset of the GLOBEX limit order system trading rules is taken from Domowitz (1990b). 1/

1. Order eligibility. A new order is eligible to be matched with a standing order, and a trade will result, whenever the following conditions occur:

    1.1 One order is a buy order and the other is a sell order.
    1.2 The two orders are for the same contract.
    1.3 The price of the buy order is greater than or equal to the price of the sell order.

2. Trade price. If an order match is possible according to the criteria of Rule 1, then the trade will take place at the price of the standing order.

3. Trade quantity. If an order match is possible according to Rule 1, then the trade will take place for a quantity equal to the smaller of the

    3.1 remaining quantity of the new order;
    3.2 remaining quantity of the standing order.

4. Maximization of total trade size. If there are multiple standing orders eligible for matching against a new order, then matching will be considered in priority sequence until one of the following conditions is attained:

1/ There also are special rules governing the setting of an opening price in the GLOBEX system, as well as a facility to directly take an existing bid or offer on the limit order book.

4.1 the new order is completely filled;
4.2 all eligible standing orders have been considered.

5. Standing order priority.

5.1 Price: for buy orders, higher price is higher priority; for sell orders, lower price is higher priority.
5.2 Quantity: a standing order for "primary quantity" has a higher priority than that for "secondary quantity" if they are both at the same price. A standing order for secondary quantity has priority over a standing order for primary quantity if the supplementary quantity is at a better price. A supplementary quantity order may be executed only in conjunction with its associated primary quantity.
5.3 Time: Within the same price and quantity type, older orders have higher priority.

The first three rules are a part of most trade execution algorithms. The term "standing order" refers to a bid or offer entered previously into the system, which has been saved on the electronic order book. The fact that the trade takes place at the price of the standing order replicates floor trading practice. Variations of rule 4 are not independent of priority rules, and are considered below in that context. A possible alternative would be to have some kind of sharing rule among all orders at the same price, regardless of time of order entry.

There are three priority rules that govern this execution algorithm. Best price (5.1) is the chief priority. Following price is time: first in, first out. The final priority is one of display. A trader may split a bid or offer at the same price into primary and secondary amounts. The primary quantity is shown to all system participants. The secondary quantity is not displayed. The displayed quantity has precedence over that which is not displayed. If a trader's secondary quantity cannot be executed at the same time as the primary, the system will cancel the secondary bid or offer, as undisplayed orders have zero priority if they stand alone without some displayed quantity.

The purpose of this section is to describe the trade execution priority rules used in practice. 1/ In principle, all automated trade execution systems can be characterized by an ordered list of such rules. The list below is not ordered in any particular fashion, however.

1/ Harris (1990) also discusses selected order precedence rules, but more from a normative point of view with an eye towards improvements of rules in efforts to increase liquidity in the market. The list here is more comprehensive, but covers only rules currently used on existing systems.

P1. Price

Best price is the highest priority on virtually all systems. Trade matching systems which take transactions prices from a market exogenous to the system do not have this rule built into the algorithm, except in the indirect sense that the price at which the trade match occurs is the best quote available in the exogenous market.

P2. Price with market maker exposure

In some systems, market makers constitute a class of system participants with responsibility to execute part of retail customer order flow. Certain mechanism designs incorporate the feature that an order is exposed to the market maker for a few seconds to allow the possibility of bettering the existing best quote in the market. If the market maker declines to do so, the order is rerouted for execution at the existing quote structure, in accordance with any other priority rules. BEACON, SCOREX, MAX, and NSTS all contain this feature.

P3. Time

Time priority means first in, first out, but almost always refers to time at a particular price, not time in the system. Even time at price is not always a sufficient description. GLOBEX, for example, allows suspension of orders at a given price, which sacrifices time priority when the order is reactivated.

P4. Modified time

Modified time priority is used with quantity allocation rules, described below. Several traders may have bids outstanding at the same price. Modified time priority would give preferential treatment in terms of quantity allocation to the trader with the highest time priority order, while treating the remaining participants equally, in the case of an incoming offer eligible for matching. The APT and the proposed HKTS use a modified time priority rule.

P5. Order type

Order types include market orders, limit orders, block orders, and cross orders. Cross orders refer to two orders from the same system participant, a buy order and a sell order for the same quantity at the same price. 1/ The HKTS will give higher priority to such orders, as does SAX. SOFFEX has special procedures to deal with crosses. Block orders refer to bids or offers above some specified quantity. Block order priorities are treated under quantity priority below. Market orders, i.e., orders to buy

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1/ The idea here is that the system trader has received such orders from two retail customers who do not have direct access to the system.

or sell at the best current quotes, almost always have priority over priced limit orders. They are not allowed in some systems, GLOBEX, for example.

P6. <u>Quantity</u>

Size precedence gives priority to bids or offers for large quantity. Such a priority rule would generally displace a time priority rule. The SOFFEX block trading facility imposes a size priority for trades above a certain quantity, but subject to numerous qualifications.

P7. <u>Quantity allocation</u>

Size allocation priorities pre-empt time priority or are used with a modified time rule. The system may, for example, allocate an equal number of shares or contracts of an incoming eligible offer to each system participant bidding at the same price until the incoming order is filled or all bids with prices eligible for matching are exhausted. Alternatively, the system can allocate incoming orders to eligible system bidders on a pro rata basis, i.e., according to the quantity bid. The Stock Exchange of Hong Kong is currently debating the form of allocation mechanism for the proposed HKTS. APT is a pro rata allocation system.

P8. <u>Display</u>

There are two possible types of display precedence. The first may be classified as a rule which gives priority to bids and offers which display the size of the order and the identity of the trader over orders which hide identity. Systems to date either give trader identification or they maintain anonymity, but do not prioritize this way. The second gives priority to bids and offers whose size is displayed to the market over orders that are submitted, but not displayed to the system participants. Such a feature favors traders who disclose their order information to the market. GLOBEX, CATS, and NORDEX embody this type of priority rule.

P9. <u>Trader class</u>

It is customary in U.S. equity markets to give public limit orders precedence over specialist, market maker, or dealer quotes at the same price, regardless of time precedence. 1/ Although this rule would be easy to implement on any electronic system, only NSTS, HKTS, and ATS/2 on the list presented in section II appear to have this feature. 2/

1/ See Harris (1990) for discussion.
2/ There is some ambiguity in this case as well. Trading rules for ATS/2 specify this class distinction explicitly, but it is not clear that it is enforced as part of the trade execution algorithm.

P10. Preferencing

Preferencing is the practice of routing a customer's orders to a particular system participant by prior arrangement. Preferencing rules on SOES, MAX-OTC, and SAEF require preferenced orders to be executed at the best quote of any dealer in the market, regardless of whether the preferenced dealer is offering the best price. 1/

P11. Hit and take

Hitting the bid or taking the offer refers to an action, rather than a priority, but a description of systems in terms of priority rules would be incomplete without it. It is an action which may supersede other priorities, and its role in the trade matching process is discussed in the next section. Not all systems have such a feature. Those that do include GLOBEX, APT, SYCOM, SOFFEX, IBIS, and INSTINET.

All continuous automated auction systems currently in place can be characterized in terms of an ordering of these priorities. The GLOBEX algorithm presented at the first part of this section could be given as (P1, P3, P8, P11). Systems such as FAST, ATS, and FACTS are simply (P1, P3) priority mechanisms. MOFEX is written as (P1, P5, P3). A complete classification of algorithms is contained in Tables 4 through 6.

Some rules clearly are less prevalent than others. Although Harris (1990) argues strongly for display precedence as an essential system feature, only 5 percent of futures/options systems and 8 percent of stock/bond systems embody such a rule. Preferencing is completely absent in futures markets, and appears only in 12 percent of stock systems. Quantity or quantity allocation rules did not appear in stock systems until after 1989, perhaps due to the tradition of upstairs block trading in floor-based markets, although 10 percent of the futures/options systems contain this feature. 2/ Priority related to order type is focused in stock systems, accounting for part of the design in about half of these, while less than 20 percent of futures/options systems contain this feature.

The statement of priority rules is a bit terse, and some distinctions and elaborations in terms of design deserve mention. The price improvement offered by the market maker exposure in rule P2 can be automated, for example. This is taken up in the next section.

Hitting the bid or lifting the offer is not equivalent to a market order. Market orders operate in electronic systems precisely the same way as they do on the floor, in that a market order is assured execution.

1/ See Stoll and Huang (1990) for a discussion of the advantages and disadvantages of preferencing arrangements.

2/ In this context, it should be noted that most stock systems built prior to 1987 were designed for small orders only.

Table 4. Classification of Futures/Options Systems by Priority Rules

System	Trade Matching Priorities				
GLOBEX	P1	P3	P8	P11	
ATS/2	P1	P3	P9		
FAST	P1	P3			
APT	P1	P4	P7	P11	
ATS	P1	P3			
SYCOM	P1	P3	P11		
FACTS	P1	P3			
DTB	P1	P3			
S-MART	P1	P5	P3		
MOFEX	P1	P5	P3		
SOFFEX	P1	P5	P6	P3	P11
CORES-F	P1	P3			
CORES-O	P1	P3			
SFTS	P1	P3			
OTS	P1	P3			
TGE	Automated single price auction				
RAES	P3				
AUTO-EX	P3				
POETS	P3				
AUTOM	P3				
SOM	P1	P5	P3		

Table 5. Classification of Stock/Bond Systems by Priority Rules

System	Trade Matching Priorities				
SEATS	P1	P3			
CAC	P1	P3			
IBIS	P1	P11			
GTB	P1	P5	P3		
MORRE	P3				
SAEF	P3	P10			
SIB	P1	P5	P3		
BEACON	P3	P2			
NSTS	P1	P9	P2	P3	P8
MAX	P3	P2			
ABS	P1	P3			
OHT	P3				
SCOREX	P3	P2			
PACE	P3				
SOES	P3	P10			
CORES	P1	P3			
STS	P1	P3			
CLOB	P1	P3			
CATS	P1	P5	P8	P3	
HKTS	P1	P9	P5	P4	P7
ELECTRA	P1	P3			
MATCHMAKER	P1	P5	P3		
MAX-OTC	P3	P2	P10		
SAX	P5	P1	P3		
OLS	P1	P5	P3		

Table 6. Classification of Proprietary Systems by Priority Rules

System	Trade Matching Priorities		
INSTINET	P1	P3	P11
BEST	P1	P3	P11
TRADE	P1	P3	P11
NORDEX	P1	P3	P8
WAS	Automated single price auction		
POSIT	P3	P6	
DELTA	P11		

Hitting the bid, for example, involves touching a button that signals acceptance of some or all of the size of a bid at some price, usually the best bid. If two traders react to a bid on the screen by touching the button, only the first to hit the bid will receive execution, with time measured in nanoseconds.

This is not to say that real time trading via market orders is not allowed on automated systems. Market orders can and are processed against quotes from the limit order book, as well as market maker quotes, on many systems. The hit/take option is supplementary to market orders in these cases. In a limit order only system such as GLOBEX, this option is a primary means of direct market interaction.

Real time revision of orders is permitted on all systems, including cancellation. Cancellation and resubmission of bids and offers sacrifice time priority. Suspension of orders, as mentioned in rule P3, is a form of temporary cancellation with the option of simultaneous resubmission of all orders, given that price and size are unchanged.

Finally, precedence with respect to trader class refers to the origin of an order, and not to rules dictating the types of individuals allowed to interact directly in the system. For systems operated by exchanges, direct participation is heavily restricted, in much the same way as entry to the floor. The purchase or lease of a seat often is required. Training programs are offered and examinations must be passed, in the interest of orderly markets. For proprietary systems, capital requirements usually are the only impediment to system trading.

IV. Classification by Degree of Automation of Price Discovery

The degree of automation of the price discovery process dictates the amount of interest in the economic efficiency of any given algorithm. The potential for efficiently discharging the fundamental task of price discovery in financial markets by computerized systems has been formally recognized since 1963. 1/ There is considerable diversity in how this task is carried out, however. The purpose of this section is to characterize these differences, based on the algorithmic nature of the trade execution process.

The nature of the trade matching rule and the ordering of execution priorities are necessary, but not always sufficient, to determine the degree of automation of price discovery. The following steps are based on an analysis of the systems listed in section II. They are ranked in order from the lowest degree of automation to the highest.

1/ See Special Study of Securities Markets, Report of the Special Study of the Securities and Exchange Commission (1963), in H.R. Doc. No. 95, 88th Congress, 1st Session, pp. 358 and 678.

D1. Price taken from another market

The earliest systems perform trade matching based on time and order type priorities, with the transaction price determined from a floor or telephone market operating at the same time. There is no price discovery mechanism. For example, RAES operates in tandem with the options trading floor of the Chicago Board of Options Exchange. The crowd in the pit is trading continuously, and the best bid and offer outstanding on the floor at any given time are transmitted to RAES, providing prices at which system orders are executed. 1/ Execution takes place against a limit order book or directly against a specialist, dealer, or market maker, often on a rotating basis. 2/ Such systems typically provide automated execution for limited sizes of orders. Some mechanisms of this type expose the incoming system order to a floor trader, typically the specialist or a market maker, for a few seconds in order to allow the trader to improve the existing quote, if market conditions permit. This is a form of manual interference with the execution process, however, and such systems still must be considered as lacking a price discovery mechanism.

D2. Price from another market with a price improvement algorithm

The manual exposure of orders to a market maker for price improvement can be automated. Some automated systems execute trades based on a consolidated best bid or offer from multiple markets. The guaranteed execution price of small orders is the best price from all markets, but the order may be transacted at an even better price, depending on the size of the bid-ask spread and market conditions.

The Midwest's SuperMax and Enhanced SuperMax constitute the only real working models of automated price improvement. The basic idea can be illustrated with the SuperMax rules, which are simpler than those of Enhanced SuperMax. 3/ The algorithm is as follows:

(i) Buy/sell orders in 1/8 wide markets and orders not meeting criteria (ii) and (iii) below execute at the consolidated best bid and offer (CBO).

1/ See Domowitz (1990b) for a complete description of such systems, and an analysis of welfare losses potentially incurred by trade matching and assignment systems of this type.

2/ Different forms of rotation are discussed in Domowitz (1990b). The rotation can be affected by the quotes offered by the dealer or market maker at the time of submission of the system order, for example.

3/ Enhanced SuperMax is a form of automated stop procedure, the manual form of which is used by specialist's on the NYSE. See Domowitz and Wang (1992) for a description of the rules governing Enhanced SuperMax, and the NYSE Floor Official Manual, June, 1991, p. 16, for an explanation of stopping rules.

(ii) Buy orders of less than 599 shares in markets wider than 1/8 execute at a price 1/8 better than the CBO if

(a) an execution at the CBO would create a double uptick based on the last sale in the primary market; or
(b) execution at the CBO would result in greater than a 2/8 price change from the last sale in the primary market.

(iii) Sell orders of less than 599 shares in markets wider than 1/8 execute at a price 1/8 better than the CBO if

(a) execution at the CBO would result in a double down tick based on the last sale in the primary market; or
(b) execution at the CBO would result in greater than a 2/8 price change from the last sale in the primary market.

Thus, an order is never transacted at a price worse than the best bid or offer across markets, but may receive improved pricing based on the impact on current market conditions. This represents a step up in the automation of price discovery, in that the computer assesses market conditions and prices the trade accordingly for execution against the specialist, dealer, or market maker.

D3. Some negotiation capability exists in the system

Certain mechanisms allow direct, albeit often anonymous, negotiation between potential buyers and sellers, in an otherwise fully automated system. Negotiation options generally are determined by order size in such cases, being reserved for large blocks of securities. In SOFFEX, for example, although there exists a special automated execution facility for priced blocks, it also is possible to advertise desired quantity without a price, inviting negotiation. Once a price is agreed upon, the block is electronically executed. This price, however, has an impact on executions from the regular limit order book, under the SOFFEX quantity priority rules for the participation of small orders in block trades. In that sense, negotiation dilutes the degree of automated price discovery even for orders which are executed without benefit of negotiation.

D4. Direct removal of quotes from the trading screen

Direct removal of quotes refers to the capability of hitting a bid or lifting an offer shown to the market, as discussed in section III. This action is not equivalent to a market order. Different versions of this option can exist in various systems. The most common is to limit the electronic keystroke to the best bid or offer, for example, for all or part of the size advertised at the best price. GLOBEX offers the alternative of submitting a sell price, say, indicating that the trader will sell all quantity offered at prices down to the price indicated. Such a variation is very similar to straight limit order submission, however. Price discovery is most affected by the manual intervention allowed by hit/take keystrokes in the case of a system embodying quantity allocation priority rules.

D5. Automated continuous double auction

ɜutomated continuous double auction systems, transactions occur when the orders cross; i.e., when the price of the best offer to buy is equal to or greater than that of the best offer to sell. Price is determined endogenously within the system, based on order flow and the priority rules. The GLOBEX example of the last section is one such mechanism, and this form of design is becoming the most common in practice. Market orders are executed against quotes from the limit order book on many systems.

D6. Automated continuous double auction with pricing model

It is possible to conduct an auction in units other than price. In particular, a volatility quote is an alternative means of quoting options, by bidding or offering the implied volatility of the underlying security. For the purpose of trade matching, a volatility quote is treated like any other price, and all the same rules and priorities apply with respect to execution. Following execution, a price is determined from an option pricing model, using real-time capture of the price of the underlying security and interest rate, as well as time to expiration and the strike price, as additional inputs to the pricing algorithm. The price is used to calculate the amount due to the purchaser of the option contract, and is considered fungible with respect to options prices from standard price auctions for the purpose of clearing and settlement.

The motivation for this kind of auction stems from concerns over stale quotes in options markets, where the underlying price and interest rate may change too quickly for traders to adjust multiple quotes in an automated environment. Options trading decisions most often are based on volatility estimates, which change slowly relative to shifts in the price of the underlying security. GLOBEX recently applied for permission to inaugurate volatility trading, noting that the method is similar to trading in the over-the-counter market in interbank currency options. 1/

D7. Automated periodic single-price auction

Automated periodic single-price auctions are automated forms of the clearing house auction discussed in Friedman (1992). The only markets wholly organized around this design are the WAS and TGE, but virtually all automated continuous double auction markets use the clearing house auction for the market opening. Bids and offers are submitted over some period and executed together at a single price at a single point in time. The price is

1/ See letter to Jean A. Webb, Commodity Futures Trading Commission, from Todd Petzel, Chicago Mercantile Exchange, dated 21 June, 1991, and Federal Register, vol. 56, no. 147, 31 July, 1991.

calculated by minimizing the total bid/offer size imbalance and/or by maximizing the total volume traded over possible transactions prices. This design might be considered the most automated in terms of price discovery, weighing revealed supply and demand conditions in order to arrive at the transactions price.

Unlike the ideal Walrasian tatonnement procedure, some bids or offers eligible for trade at the chosen price cannot be executed because supply will not precisely equal demand, an effect largely due to the imposition of a discrete minimum price variation. In this case, some priority ordering must be used to decide what trades should be executed. Market orders often are executed first, followed by priced orders in order of price and time.

In practice, existing automated trade execution systems often embody some combination of these levels of automation. Tables 7, 8, and 9 contain a classification of systems along these lines for futures/options, stock/bond, and proprietary systems, respectively. 1/ In the tables, D1' refers to level D1 combined with manual exposure to a market maker or specialist on the exchange. Such combinations account for 45 percent of all systems operating at level D1. Systems without a price discovery mechanism, in the sense of D1, are far more prevalent on stock exchanges than in futures/options markets. About 40 percent of stock systems lack endogenous price discovery, compared to 19 percent of futures/options systems.

This observation is modified by looking at the age profile of systems. Of the automated exchanges constructed after 1989, 71 percent of both futures/options and stock/bond systems are classified as level D5 or greater, indicating automation of the auction process itself. That percentage is the same for futures/options markets regardless of age, but only 60 percent of automation on stock exchanges is at D5 overall.

There are pronounced differences in the level of automation across broad geographical groups of market centers. In futures and options, only 1 in 5 systems in the United States is classifiable as level D5 or above. The figure jumps to 88 percent in Europe, with the only other system operating as a pit trading simulation at level D4. Fully 100 percent of systems in the Pacific region are classified as level D5 or greater. For stocks and bonds, only 10 percent of U.S. systems exhibit automated price discovery. In comparison, 86 percent of European exchanges and 100 percent of Pacific exchange systems are automated at level D5 or above. Two of the three systems operating in Canada also achieve this degree of automation. Some of these differences again are due to the age profile of systems, with U.S. systems generally being a bit older.

1/ As noted previously, automated continuous double auctions virtually all use the clearing house auction to open trading. This is omitted in the tabular descriptions, and only systems employing the clearing house auction as a primary means of trading are classified as such.

Table 7. Classification of Futures/Options Systems by Degree of Automation of Price Discovery

System	Levels of Price Discovery Automation		
GLOBEX	D4	D5	D6
ATS/2	D5		
FAST	D5		
APT	D4		
ATS	D5		
SYCOM	D4	D5	
FACTS	D5		
DTB	D5		
S-MART	D5		
MOFEX	D5		
SOFFEX	D4	D5	D3 (blocks only)
CORES-F	D5		
CORES-O	D5		
SFTS	D5		
OTS	D5		
TGE	D7		
RAES	D1		
AUTO-EX	D1		
POETS	D1		
AUTOM	D1		
SOM	D5		

Table 8. Classification of Stock/Bond Systems
By Degree of Automation of Price Discovery

System	Levels of Price Discovery Automation		
SEATS	D5		
CAC	D5	D3 (blocks only)	
IBIS	D4	D5	
GTB	D5		
MORRE	D1		
SAEF	D1		
SIB	D5		
BEACON	D1'		
NSTS	D1'	D4	D5
MAX	D1'	D2 (SuperMax only)	
ABS	D5		
OHT	D1		
SCOREX	D1'		
PACE	D1		
SOES	D1		
CORES	D5		
STS	D5		
CLOB	D5		
CATS	D5		
HKTS	D5		
ELECTRA	D5		
MATCHMAKER	D5		
MAX-OTC	D1'		
SAX	D5		
OLS	D1		

Table 9. Classification of Proprietary Systems
By Degree of Automation of Price Discovery

System	Levels of Price Discovery Automation		
INSTINET	D4	D5	D3
BEST	D4	D5	
TRADE	D4	D5	
NORDEX	D5	D3	
WAS	D7		
POSIT	D1	D3	
DELTA	D4	D3	

Few systems classified as exchanges, or components thereof, allow negotiation, anonymous or otherwise. CAC and SOFFEX are the exceptions, and bargaining capability is reserved for large blocks of securities. Proprietary systems exhibit this feature more predominately, however, with 3 of the 7 systems allowing negotiation between parties.

V. Classification by Information Structure

A full discussion of information structure and system transparency requires consideration of information flow to three broad classes of market participants: system traders, public investors, and regulators. Attention is restricted to system traders and the public, as they constitute the sources of trading activity. Regulators can be provided with virtually any kind of information conceivable at low cost, due to the computerized nature of the system. 1/

Data potentially available to system users in real time for any individual security includes:

high price and low price of the trading session
price and size of the latest trade
the best bid and offer prices (BBO)
quantities available at the BBO
prices of all bids and offers in the system
the size available at all prices
trader identification for each quote
counterparty identification for each trade
sales record of the session
aggregate volume traded in the session
number of system participants or terminals active
relevant information from other markets

This list excludes information potentially available to a system user that ordinarily would be considered private. The position of a trader in any or

---

1/ The types of information discussed in this section also differ in many respects from those commonly analyzed in the theoretical literature on auctions and market microstructure. Systems do not provide private signals containing information leading to the formation of reservation values. All system signals are common, with the exception of an individual trader's position in the security. This is not the same as the common values assumption discussed in Friedman (1992), however. Under that assumption, traders receive independent unbiased signals concerning an uncertain reservation value. To the extent that the trading process disseminates private information, systems differentiated with respect to their communication technology have varying effects on market efficiency in the sense of information-theoretic models of trading.

all securities traded is one example. A classification of systems with respect to information provided to direct system participants, i.e., system traders, is given in Tables 10 through 12.

Despite the fact that an automated system could offer all data listed above, since the computerization of the trading process requires or produces it, 1/ systems vary widely with respect to information display. The simplest designs literally have no display of their own. These systems are limited to trade matching algorithms which operate according to time priority only, and use prices from outside the system as transaction prices. Price information and quotation display must be obtained from quote vendors servicing the outside market generating prices. Such systems include AUTOM, RAES, AUTOEX, POETS, BEACON, MAX, SCOREX, PACE, and SOES.

General market information concerning last trade and aggregate volume, for example, is available on most systems that produce such information as part of the trade execution process. Information from other markets is part of few systems, on the other hand. It would be natural to expect that such data be part of systems for the trading of derivative securities, and not necessarily for stocks. All derivative systems except for GLOBEX and SOFFEX lack this feature. The presumption is that the exchanges do not want to be held responsible for lags in information coming from other markets. 2/ On the other hand, some stock systems link several regional markets. SEATS connects six markets in Australia, while NSTS links regional stock exchanges and the NYSE in the United States. Both systems display information from all markets.

Screen-based trading systems are anonymous for the most part. Few offer identification of system users posting bids and offers to system participants. Only 6 percent of futures/options systems display personal identifiers for quotes, while 15 percent of stock/bond systems do so. Systems showing such identifiers include CATS, APT, GTB, INSTINET, and SEATS. 3/ It is much more common to observe the availability of the counterparts to executed trades, although this sometimes is private information, limited to the parties involved in the transaction.

1/ The key exception is information from other markets in the case of the trading of derivative securities. Such information is not required or produced by the computerization of the auction, and could be obtained from other sources in real time.

2/ GLOBEX has been wrestling with this problem. Spot prices to support derivatives trading can lag system transactions prices by as much as 20 seconds, based on conversations with GLOBEX personnel. Such a lag is long by trading standards, and it is expected that the problem will be remedied before the system is officially started up.

3/ Broker identification is required in SEATS for quantities less than $10,000. Disclosure is optional for bids or offers over that amount.

Table 10. Screen Transparency: Features/Options Systems

	GLOBEX	ATS/2	FAST	APT	ATS	SYCOM	AUTOM	DTB	SMART	MOFEX	SOFFEX	CORESF	CORESO	SFTS	OTS	RAES	AUTOEX	POETS
High Price	•					•			•			•	•	•	•			
Low Price	•					•			•			•	•	•	•			
Last Price	•	•	•		•	•		•	•	•	•	•	•	•	•			
Size of Last	•					•												
BBO		•	•	•	•	•			•	•	•							
BBO Size		•	•	•	•	•			•	•	•							
Book Prices	•							•				•	•	•	•			
Book Sizes	•							•				•	•	•	•			
Hidden Size	•			•														
Quote IDs				•														
Counterparty	•			•		†												
Other Markets	•										•							
Sales Record									•		•							
Volume	•	•	•	•		•			•	•	•	•	•	•	•			

† Counterparties to last trade in system displayed.
■ No quotation or price display: Market Information through vendors only.

Table 11. Screen Transparency: Stock/Bond Systems

	SEATS	CAC	IBIS	GTB	MORRE	SIB	SAEF	BEACON	NSTS	MAX	ABS	OHT	SCOREX	PACE	SOES	CORES	STS	CLOB	CATS	HKTS
High Price		●	●			●										●	●			
Low Price		●	●			●										●	●			
Last Price	●	●	●	●	●	●			●		●					●	●	●		●
Size of Last	●	●									●									●
BBO	●						●													
BBO Size	●						●													
Book Prices		●	●	●	●	●			●		●					●	●	●	●	●
Book Sizes		●	●	●	●	●			●		●					●	●	●	●	●
Hidden Size																		●	●	●
Quote IDs	¤			●															●	
Counterparty	●	●		●		●	●												●	
Other Markets	●		●						●											
Sales Record	●					●													●	●
Volume	●	●	●	●	●	●					●					●	●			

¤ Broker ID for quantity less than $10,000 mandatory; disclosure optional for over $10,000.
■ No quotation or price display: market information through vendors only.

Table 12. Screen Transparency: Proprietary Systems

	INSTINET	BEST	TRADE	NORDEX	WASI	POSIT	DELTA
High Price	●						
Low Price	●						
Last Price	●	●	●		‡		
Size of Last	●				‡		
BBO				●			
BBO Size				●			
Book Prices	●				●		●
Book Sizes	●				●		●
Hidden Size		●	●				
Quote IDs	●						
Counterparty		●	●				
Other Markets				●			
Sales Record				●			
Volume	●				●		

‡ Here, last denotes continously updated indication of single market auction price and quantity.

▪ Participants specify how much information to show the market; possible to show only selected parties order information.

The major informational difference between systems that has potential importance for pricing and market efficiency is the availability of current bid and offer information. Many systems do not display the book of bids and offers to all system participants, giving only the best bid and offer in real time. There is a real difference between futures and stock systems in this regard. Of the futures/options systems with nontrivial system displays, 38 percent show the book, or at least a meaningful number of the best bids and offers. On the other hand, 86 percent of automated stock exchanges and 50 percent of propriety stock trading mechanisms display the book. Further, several systems allow bids and offers into the system that are not shown to market participants. These include GLOBEX, APT, CLOB, CATS, and NORDEX. There is little difference between futures and stock systems here, however, with 15 percent of futures systems and 21 percent of automated stock exchanges allowing hidden size.

Not all system participants are treated equally with respect to information in some designs. Such informational differences appear to be limited to trader identification. NSTS offers a "public" limit order book with aggregate quote information to system traders, while designated market makers have a screen available which shows all market maker quotes, identified individually by dealer. CAC has three levels of information, providing quote and trade identification information only to brokers.

Substantial asymmetries exist between information provided to direct system participants and that given to outside investors who submit orders to traders or brokers on the system. Tables 13 through 15 contain a listing of public information from futures, stock, and proprietary systems for which such data could be gathered. A comparison of these tables with tables 10 through 12 indicates the major differences are to be found in the provision of quotation and trader identification information. No trader identification information is given to the public, even for systems in which trading is not anonymous. The degree of informational asymmetry in quotation data is a function of the type of security traded.

Examination of the list of stock/bond exchange-based systems for which information on both public and trader data is available shows that 91 percent of such mechanisms show the limit order book to system traders. Only 27 percent of these computerized markets give the same information to the public. 100 percent of the stock systems exhibit the best bid and offer to traders, while 73 percent make the best quotes available to outside investors. The figures are substantially different for futures and options systems. Of the markets for which both public and trader information is available, 56 percent of the systems show the book to traders. No system provides book data to the public. Further, a full 56 percent of systems do not even make the best bid and offer available to outside investors. Proprietary systems exhibit similarly radical, but perhaps more understandable asymmetries, in that proprietary markets do not exist to serve the public in any way. Of those that can be compared with respect to both kinds of information, 100 percent of systems provide detailed quotation

Table 13. Public Information : Futures/Options Systems

	GLOBEX	SYCOM	AUTOM	SMART	MOFEX	SOFFEX	CORESF	CORESO	SFTS	OTS	RAES	AUTOEX	POETS
Sales Record				●			o	o	o	o			
Low Price				●			o	o	o	o			
Last Price	●	●	●	●	●	●	●	●	●	●	●	●	●
Size of Last													
BBO	●	●	●	●	●	●					●	●	●
BBO Size	●			●	●	●							
Book Prices													
Book Sizes													
Identification													
Sales Record				●									
Volume		●	●	●	●	●	●	●	●	●	●	●	●

o Supplied on a daily basis.

Table 14. Public Information: Stock/Bond Systems

	SEATS	CAC	IBIS	GTB	MORRE	SIB	BEACON	NSTS	MAX	ABS	OHT	SCOREX	PACE	SOES	CORES	STS	CATS
High Price	○			○		●									○	○	
Low Price	○			○		●									○	○	
Last Price	●	●	○	●	●	●	●	●	●	●		●	●	●	●	●	●
Size of Last		●		●			●	●	●	●		●	●	●			
BBO	●			●		●	●	●	●			●	●	●			
BBO Size	●					●	●	●	●			●	●	●			
Book Prices					●					●							●
Book Sizes					●					●							●
Identification																	
Sales Record						●											
Volume	●		○	●	●	●					●				●	●	

○ Supplied on daily basis.

Table 15. Public Information: Proprietary Systems

	INSTINET	WASI	POSIT	DELTA
High Price				
Low Price				
Last Price	●	●	●	
Size of Last	●	●	●	
BBO				
BBO Size				
Book Prices				
Book Sizes				
Identification				
Sales Record	●		●	
Volume		●		○

○ Supplied on a daily basis.

information to system traders, while no system provides any quotation information to the public.

The design of the screen display obviously depends on the information to be made available, but also differs depending on the market served by the automated system. Several examples are provided in Figures 1 through 7.

Figure 1 illustrates the general layout of the GLOBEX screen. GLOBEX is a futures and options system, and the monitor window displays information on current prices in the underlying spot markets. The alerts window serves as a signaling device to an individual trader, and can be programmed to alert the system user when the price of a contract reaches a certain level, for example. The ticker window gives real time execution information. The main trading window is broken up into four blocks of information: financial instruments monitored, market, statistics, and terminal. These blocks are illustrated in Figure 2. The market block gives the BBO with size for the instruments listed on the left of the screen. The statistics information on the normal view of the screen is limited to the price of the last transaction and the net change in price. The terminal block is personalized, containing the system user's own quotations for the instruments listed in the instrument block.

There are three other possible ways to view the main trading screen in GLOBEX, shown in Figure 3. The "statistics view" replaces the terminal block with additional market information on the instruments displayed. The "more view" again is personalized to the trader; it shows the quantities bid or offered by the user that are not shown to other users via the open limit order book. Finally, the "two-up view" replaces the statistics and terminal block with additional market information, including bid-ask spreads trading on the system.

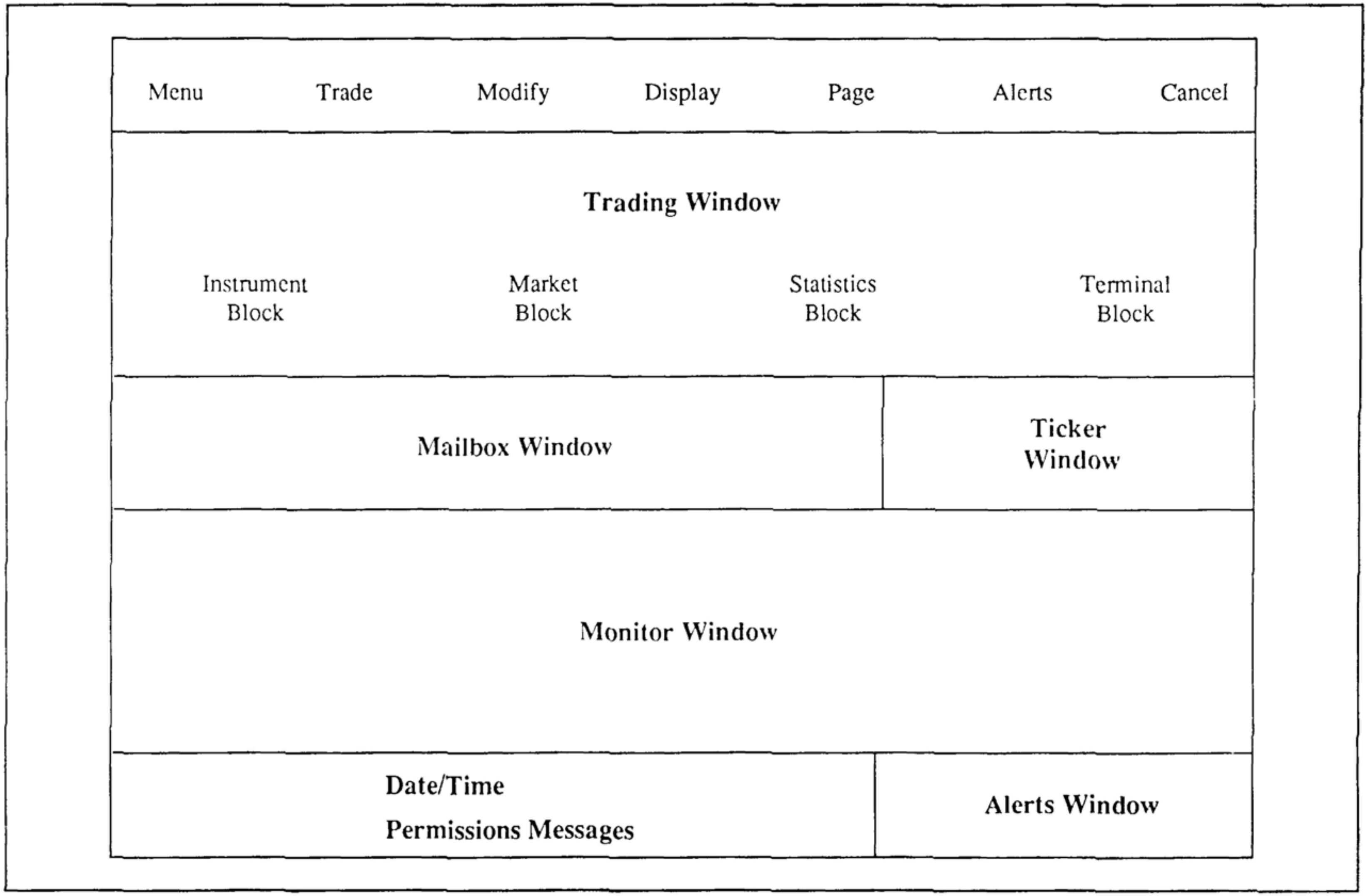
GLOBEX is a limit order system that displays the order book. 1/ It is a window option selected from a menu. A typical such window is illustrated in Figure 4, taken from the SYCOM system. Note that the book contains the aggregate size available at each price, and this is virtually universal among order book displays. 2/ The contract summary screen serves the same purpose as the instrument, market, and statistics blocks in GLOBEX. The bottom of the SYCOM main screen contains boxes corresponding to function keys on the terminal keyboard. The BBO and last trade price are illustrated for each contract selected by the user, and a press of the key allows trading screen and strategy screen information for that instrument. There is no analogue to the strategy screen on GLOBEX, because the means of entering bids and offers differ on SYCOM. Bids or offers for a single instrument are entered into the terminal, but not transmitted to the host

---

1/ More precisely, the ten best bids and offers with associated size.
2/ An exception is the market maker display in NSTS, which shows all quotes by dealer, with size for each quote.

FIGURE I

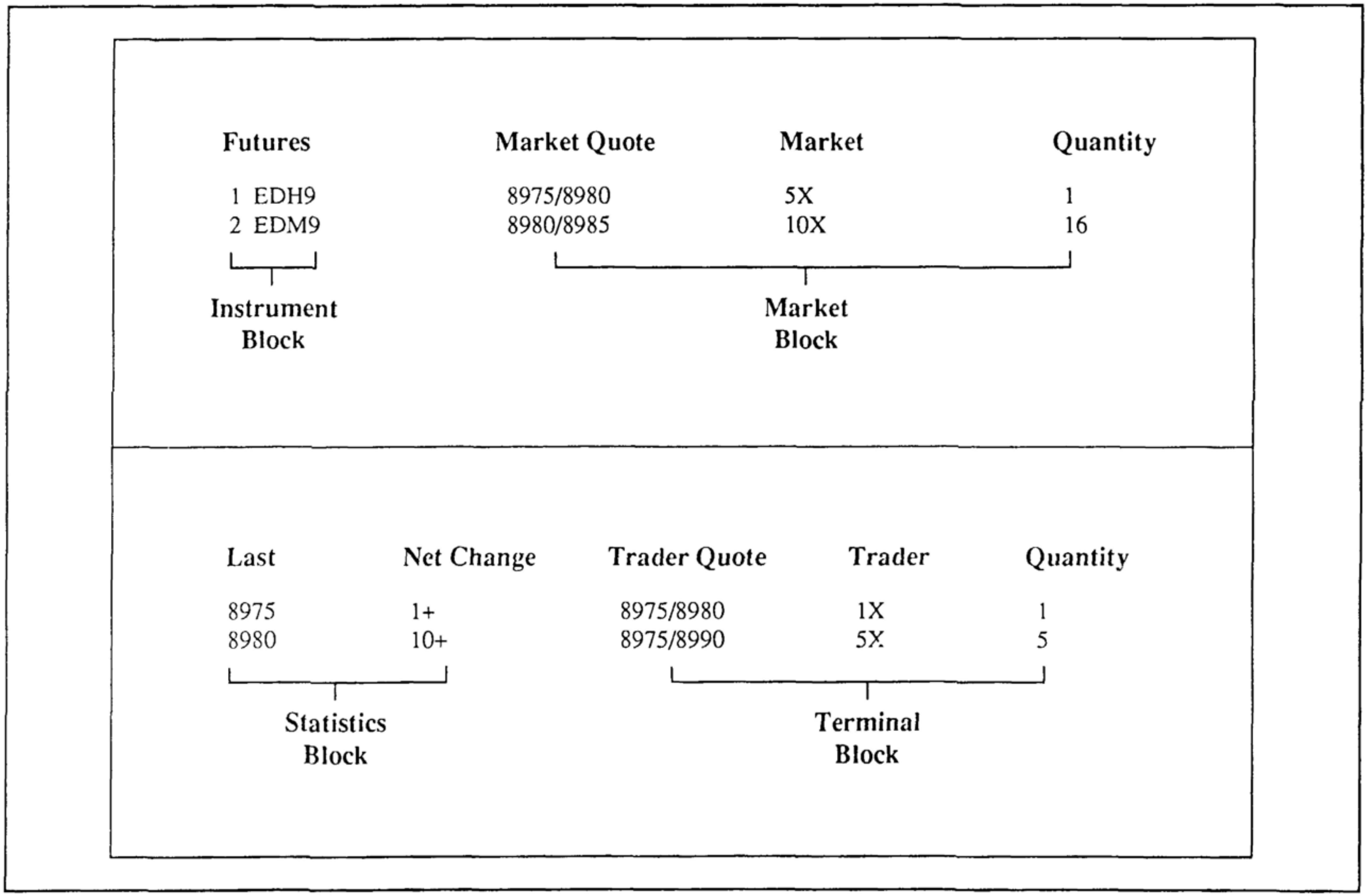
GLOBEX MAIN DISPLAY [1]



[1] Source: Globex User Guide–Beta Version.

FIGURE 2

GLOBEX TRADING WINDOW DETAIL[1]



[1] Source: Globex User Guide–Beta Version.

FIGURE 3

GLOBEX TRADING WINDOW DETAIL[1]

			High	Low	Volume
Instrument Block	Market Block	Statistics Block	8589 8990	8975 8980	542 47

"Statistics View" of Trading Window

			Trader Quote	More	Quantity
Instrument Block	Market Block	Statistics Block	8975/8980 8975/8990	1X 5X	1 5

"More View" of Trading Window

Futures	Market Quote	Market	Quantity	Spreads	Market Quote	Market	Quantity
1 EDH9	8975/8980	5X	1	12 EDH9–EDM9	-5/5	2X	6
2 EDM9	8980/8985	10X	16	13 EDV9–EDZ9	-10/-5	10X	19

"Two–Up View" of Trading Window

[1] Source: Globex User Guide–Beta Version.

FIGURE 4

SYCOM MAIN SCREEN WITH TRADING WINDOW [1]

Contract Summary

	XBZ9	XBHO	XBZ
OPN	6465	6660	280
HI	6465	6660	280
LO	6464	6659	279
VOL	66	10	12
ASK	6465	6659	280
SIZE	33	31	6
BID	6464	6659	279
SIZE	44	5	2
LST	6464	6659	279
CHG	↓ 1	↓ 1	
CLOSE	6465		

Contract –XBZ9 6464

SIZE	ASK	BID	SIZE
33	6465	6464	44
33	6465	6463	44
33	6466	6462	55
33	6467	6461	55

F1 XBZ9		**F2** XBHO		**F3** XBZ		**F9** Strategy Screen	**F10** Trading Screen
B	6464	B	6658	B	279		
A	6465	A	6659	A	280		
T	6464	T	6659	T	279		

1 Source: Sydney Futures Exchange Studies.

FIGURE 5

DTB MAIN TRADING SCREEN [1]

Tiker	BMW	FR	518.0	BMW	P480	10.0
	BMW	D480	33.0	BMW	D500	15.0
	BMW	Q550	75.0	BMW	E480	40.0
	DRB	FR	315.0	DRB	D300	20.0
Underlying	BMW	FR	LAST	518	3	
	Interest		56	Present	23	Close 515

	Call Summary					Put Summary			
	BID	ASK	SIZE	LAST	SERIES	LAST	BID	ASK	SIZE
Market Data	32	35	5x15	33	Apr. 480	10	8	10	5x10
	12	16	10x20	15	Apr. 500	35	35	37	10x20
	11	14	20x18	12	May 550	75	75	77	15x15
	38	40	10x15	40	May 480	11	10	12	30x10

Command Zone

Message Zone

[1] Source: An Introduction: The Deutsche Termin Bourse, Commerzbank AG.

FIGURE 6

CINCINNATI STOCK EXCHANGE INDEPTH MARKET DISPLAY[1]

15 last trades of the firm

RCA	5	50	@	62 1/3	OHIO
RCA	6	500	@	62	AMER

Issue: GM BID: 71 5 ASK: 71 5/8 5

National and CSE price and volume, today and previous

	Trades	Open	High	Low	Last
NAT	392900	71 3/8	71 1/2	71 5/8	71 3/8-
PREV	831500	72 3/4	73 1/8	70 1/2	70 5/8
CSE	100	71 1/8	71 1/8	71 1/8	71 1/8
PREV	13000	72 7/8	73	71 1/8	71 1/8

National best bid/offer, and price/size available at other exchanges

	Bids	Ask	Bsize	Asize
NBBO	71 3/4	71 5/8	30	30
CSE	71 1/8	71 5/8	9	30
NYSE	71 3/4	71 5/8	30	10
AMEX			0	0
BSE	71 1/4	71 5/8	1	6
MSE	71	71 5/8	1	21
TSE	71 1/8	71 5/8	1	1
PBW	71 1/4	72	1	1
NASD	71 1/4	71 5/8	1	1

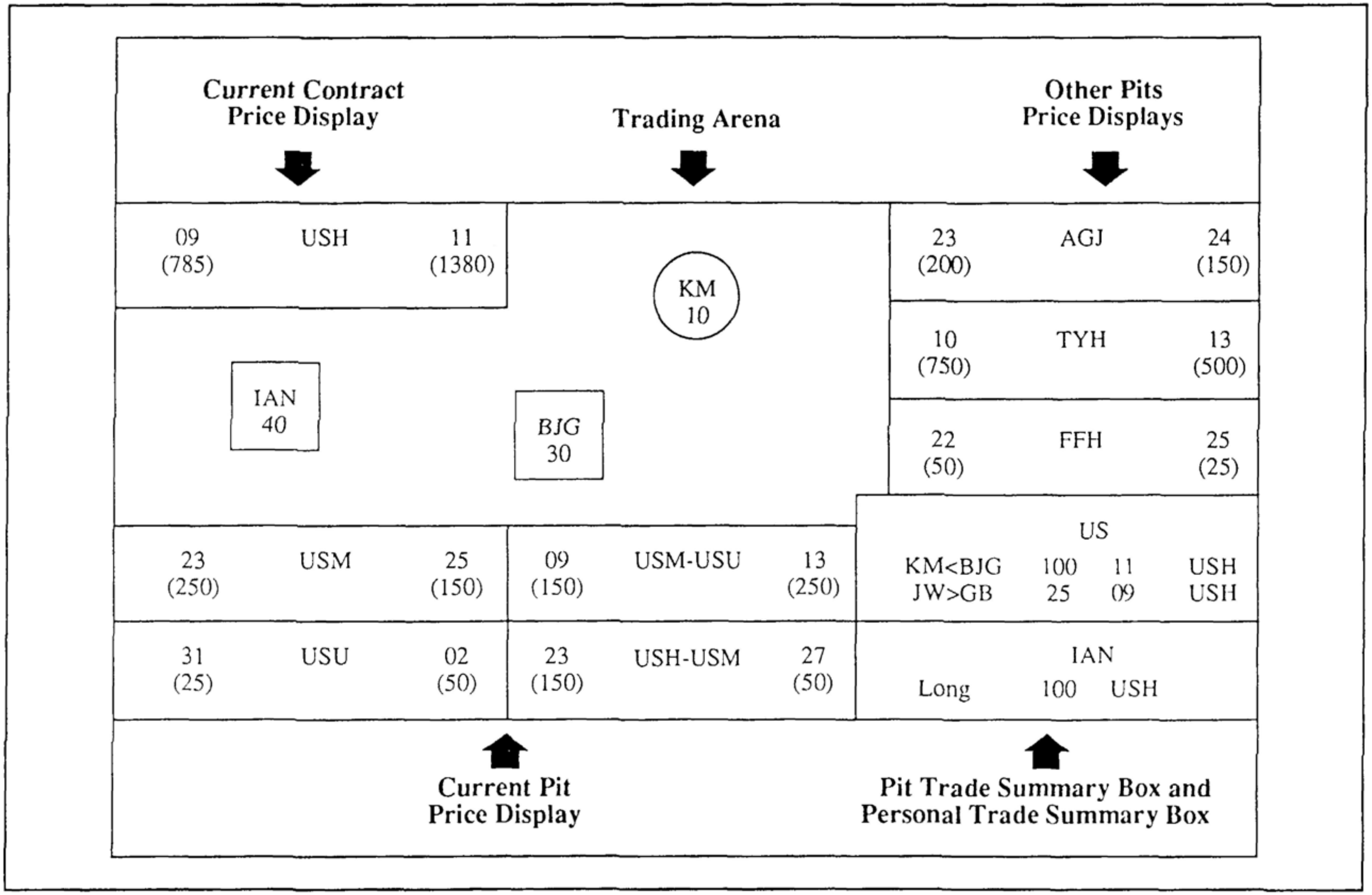
My bid	71	5
My ask	71 5/8	5
Buyers	**Bid**	**Size**
MADF	71 1/8	9
RSEC	71	5
AMER	71 1/8	5
Sellers	**Ask**	**Size**
MADF	71 5/8	30
RSEC	71 3/4	5
AMER	71 5/8	5

This block only seen by market makers

1 Source: An Overview of the NSTS Operational System at the Cincinnati Stock Exchange.

FIGURE 7

AURORA MAIN DISPLAY [1]



[1] Source: Aurora/EOS, Chicago Board of Trade.

computer immediately. 1/ This allows the trader to create a deck of orders for different securities (and/or the same security at different prices and quantities). The trader can then sequentially release several such orders simultaneously for execution. The strategy window shows the user the set of bids and offers programmed.

No information on the equities or indexes underlying the futures and options traded on SYCOM is provided by the system itself, but that feature appears on the DTB main screen in Figure 5. The ticker window here shows only the futures and options contracts traded and the last execution price. The screen does show the number of current participants, however, a feature not present in the two preceding examples.

NSTS of the Cincinnati Stock Exchange links several equity markets through the Intermarket Trading System, and offers a variety of screen displays. Figure 6 contains the screen that differentiates this system from others. The national best bid and offer is displayed, together with the best quotes on seven markets in addition to the automated market. Statistics now include national and system information for the current and previous day's trading. Finally, the box at the right contains the book seen only by designated market makers on the system, including quotes by individual dealer.

Finally, no review of terminal displays would be complete without a pit trading simulation. Figure 7 shows the screen of the Chicago Board of Trade's AURORA futures system, a market that probably will not be implemented. It is of interest, however, in that AURORA was planned to be a video simulation of the trading pit, and the icons in the center represent bids and offers with trader identification and size. The APT system was developed along similar lines. The price at which these bids and offers are made must be the best in the market, replicating pit trading. This price is shown in the upper left. The aggregate size at each price is in parentheses. The boxes on the screen border are reminiscent of screens placed around the usual trading floor. The boxes on the bottom left show contracts for the same instrument at different expiration dates and traded spreads. The ones on the right contain best bid and offer information from other simulated "pits." The position of the system user is given in the bottom right corner, while the box above contains transaction information shown to all participants, including identification of the parties making the trade.

VI. Concluding Remarks

Automated trade execution is a new and growing form of financial market microstructure. In this context, it is important to distinguish between

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1/ Contingent orders are not accepted, however, nor can orders for different instruments be spliced together.

automated trade execution and "automated trading." Automated trading is the practice of automatically transmitting orders to an exchange for execution of trades mandated by computerized contingent order strategies. So-called program trading and portfolio insurance are examples. Computerized trading was made feasible by advances in information dissemination and order routing, and certainly existed before much of the growth in automated trade execution. Program trades are not always represented and executed on the floor of the exchange as quickly as their designers might desire. Automated trade execution systems offer the potential of speeding up the process by providing computer-to-computer interfaces. Not all systems allow this, however. 1/ Further, existing automated auctions do not allow complicated contingent orders at present. The SOFFEX system provides the possibility of trading an order contingent on the execution of a single additional trade. This represents the state of the art, and most systems do not even provide such a simple feature. 2/

The taxonomy of systems provided in this paper introduces this form of market structure in a unified fashion. The comparison of mechanisms reveals systematic differences in trade execution algorithms, degree of automation of price discovery, and system transparency across financial instruments, major market centers, and over time. The diverse nature of automated markets in operation suggests that market efficiency may not be as much a function of system design as it is of environmental factors and regulatory constraints.

The work identifies areas of both theoretical and empirical interest. Informational asymmetries are uncovered with respect to system design and broad classes of market participants, which are different than those considered in the usual models of market microstructure. Such asymmetries have implications for information theoretic models of trading, and have the advantage of being observable in the markets surveyed here. The taxonomy identifies differences in design for comparison with respect to relative market efficiency. The prevalence of certain designs guides the emphasis of such research with respect to its practical importance.

1/ The NSTS system permits computer-to-computer interface, for example, but the GLOBEX system does not.

2/ This does not mean that the possibility does not exist. See Amihud and Mendelson (1985) for suggestions with respect to an auction design integrating choices among alternative auction mechanisms with a computerized portfolio management system that produces and submits many forms of contingent orders.

System Acronyms

ABS	Automated Bond System
APT	Automated Pit Trading
ATS	Automated Trading System
ATS/2	Automated Trading System, updated
AUTO-EX	Automated Exchange
AUTOM	Automated Options Market System
BEACON	BSE Automated Communications and Order Routing Network
BEST	name, no acronym
CAC	Cotation Assistee en Continu
CATS	Computerized Automated Trading System
CLOB	Consolidated Limit Order Book
CORES	Computerized Order Routing and Execution System
CORES-F	CORES for futures
CORES-O	CORES for options
DELTA	name, no acronym
DTB	Deutsche Terminborse
ELECTRA	name, no acronym
FACTS	Fully Automated Computerized Trading System
FAST	Fully Automated Securities Trading System
GLOBEX	Global Exchange
GTB	Generale Telematico di Borsa
HKTS	Hong Kong Trading System
IBIS	Integrated Trading and Information System
INSTINET	Institutional Trading Network
MATCHMAKER	name, no acronym
MAX	Midwest Automated Execution System
MAX-OTC	MAX for over the counter stocks
MOFEX	Mercado de Opciones y Futuros Financieros
MORRE	Montreal Registered Representative System
NORDEX	name, no acronym
NSTS	National Securities Trading System
OHT	Off Hours Trading
OLS	Odd Lot System
OTS	Options Trading System
PACE	PHLX Automated Communications and Execution
POETS	Pacific Options Exchange Trading System
POSIT	Portfolio System for Institutional Trading
RAES	Retail Automated Execution System
SAEF	SEAQ Automated Execution Facility
SAX	Stockholm Automated Exchange
SCOREX	Securities Communication Order Routing and Execution System
SEATS	Stock Exchange Automated Trading System
SFTS	Stock Futures Trading System
SIB	Sistema de Interconexion Bursatil
S-MART	Securities Market
SOES	Small Order Execution System
SOFFEX	Swiss Options and Futures Exchange
SOM	Stockholm Options Market

STS	Securities Trading System
SYCOM	Sydney Computerized Overnight Market
TGE	Tokyo Grain Exchange
TRADE	name, no acronym
WAS	Wunsch Auction System

Exchange Abbreviations

AMEX	American Stock Exchange
ASX	Australian Stock Exchange
BSE	Boston Stock Exchange
CBOE	Chicago Board Options Exchange
CME	Chicago Mercantile Exchange
CSE	Cincinnati Stock Exchange
CSE	Copenhagen Stock Exchange
FSE	Frankfurt Stock Exchange
GFOE	German Futures and Options Exchange
IFOX	Irish Futures and Options Exchange
LFOX	London Futures and Options Exchange
LIFFE	London Intern'l Financial Futures Exchange
LSE	London Stock Exchange
ME	Montreal Exchange
MEFF	Mercado Espanol De Futuros Financieros
MOFF	Mercado de Opciones Y Futuros Financieros
MSE	Midwest Stock Exchange
MSE	Milan Stock Exchange
NASD	National Association of Securities Dealers
NYSE	New York Stock Exchange
NZFOE	New Zealand Futures and Options Exchange
OSE	Osaka Securities Exchange
PHLX	Philadelphia Exchange
PSE	Pacific Stock Exchange
PSE	Paris Stock Exchange
SEHK	Stock Exchange of Hong Kong
SFE	Sydney Futures Exchange
SOFFE	Swiss Options and Financial Futures
SOM	Stockholm Options Market
SSE	Singapore Stock Exchange
SSE	Spanish Stock Exchanges
SSM	Stockholm Stock Market
TGE	Tokyo Grain Exchange
TIFFE	Tokyo Intern'l Financial Futures Exchange
TSE	Tokyo Stock Exchange
TSE	Toronto Stock Exchange
VSE	Vancouver Stock Exchange

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