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# A DESCRIPTION OF AN EXPERIMENTAL SECURITIES EXCHANGE

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## Abstract

A prototype of an automated securities exchange was developed, modeled after the rules and trading procedures of the New York Stock Exchange. A time-shared computer operated by the Center for Research in Management Science formed the heart of the system. The computer hardware is first described. Next, the software, termed "TF/1", and its implementation for automated trading is discussed.

The objectives in building the system were three-fold: (1) to discover what substantive changes exchange automation creates, as compared to face-to-face trading; (2) to provide a unique facility for addressing current issues in experimental finance; and (3) to provide students with a highly motivating educational experience regarding the institutional features of securities markets.

Special consideration is given to analyzing the specialist's role in an automated exchange. It is pointed out that automation clearly separates the dual roles played by a specialist, to the extent that one may reasonably question whether specialists serve any useful function in an automated exchange. Also, his discretionary activities, such as the activation of stop orders, take on interesting nuances under conditions of exchange automation.

# I. A PROTOTYPE OF AN AUTOMATED SECURITIES EXCHANGE

In the period of 1971 through 1974, the author and several research assistants[1] endevored to create a prototype automated securities exchange. Its design called for the ability to trade between each of three securities and a single risk-free asset in a continuous auction mode. Two fundamental goals motivated this project: the first was to determine exactly what trading mechanisms are necessary and desirable in an automated auction market; the second was to provide a permanent and unique facility for addressing new issues in experimental finance.

All the equipment employed was housed in the Management and Behavioral Sciences Laboratory maintained by the Center for Research in Management Science (CRMS), University of California, Berkeley. A complete description of the laboratory and its capabilities is given by Esherick, Hoggatt, and Wheeler.[2] With permission, their diagrams of the Laboratory's physical space configuration and logical

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[1]Grateful thanks are due Robert Gray, Michael Megas, and George Morrow for their insightful programming logic and continued diligence in seeing through the construction of several program versions.

[2]J. Esherick, A. C. Hoggatt, and J. T. Wheeler, "A Laboratory to Facilitate Computer Controlled Behavioral Experiments", Administrative Science Quarterly, 14 (June,1969),pp.202-207.

design have been included herein as Figures 1 and 2. Figure 3 shows a photograph of student subjects using the prototype exchange in the CRMS Laboratory.

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Figures 1, 2, 3 about here

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During the construction of the automated securities exchange, the CRMS Laboratory was itself in a state of development. The computer and the user consoles were in the process of being replaced by a state-of-the-art system. The system first employed consisted of a PDP-5 and a PDP-8 computer, referred to collectively as the PDP-5/8 system. The PDP-5/8 system was connected via twisted-pair lines to ten console stations in the adjoining flexible space, each console station terminating in a Model 33 Teletype machine. The reader is referred to Figure 2 detailing the logical structure of the hardware devices comprising the PDP-5/8 system.

The software of the automated securities exchange was originally implemented by a set of programs known as Trading Floor/1, or simply TF/1. These programs were written in the

Figure 1 (draft)

and Behavioral
Management Science Laboratory

FLOOR PLAN

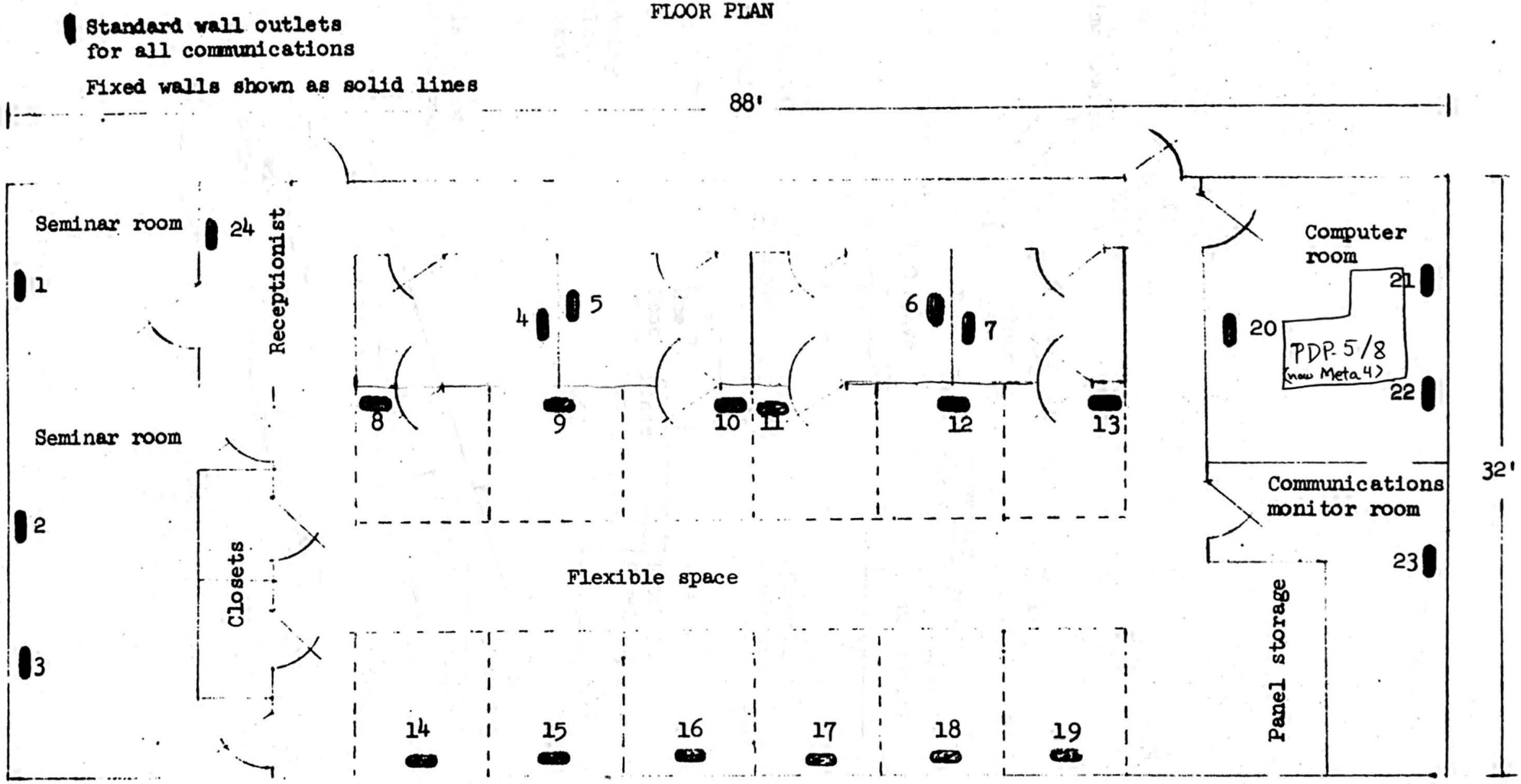
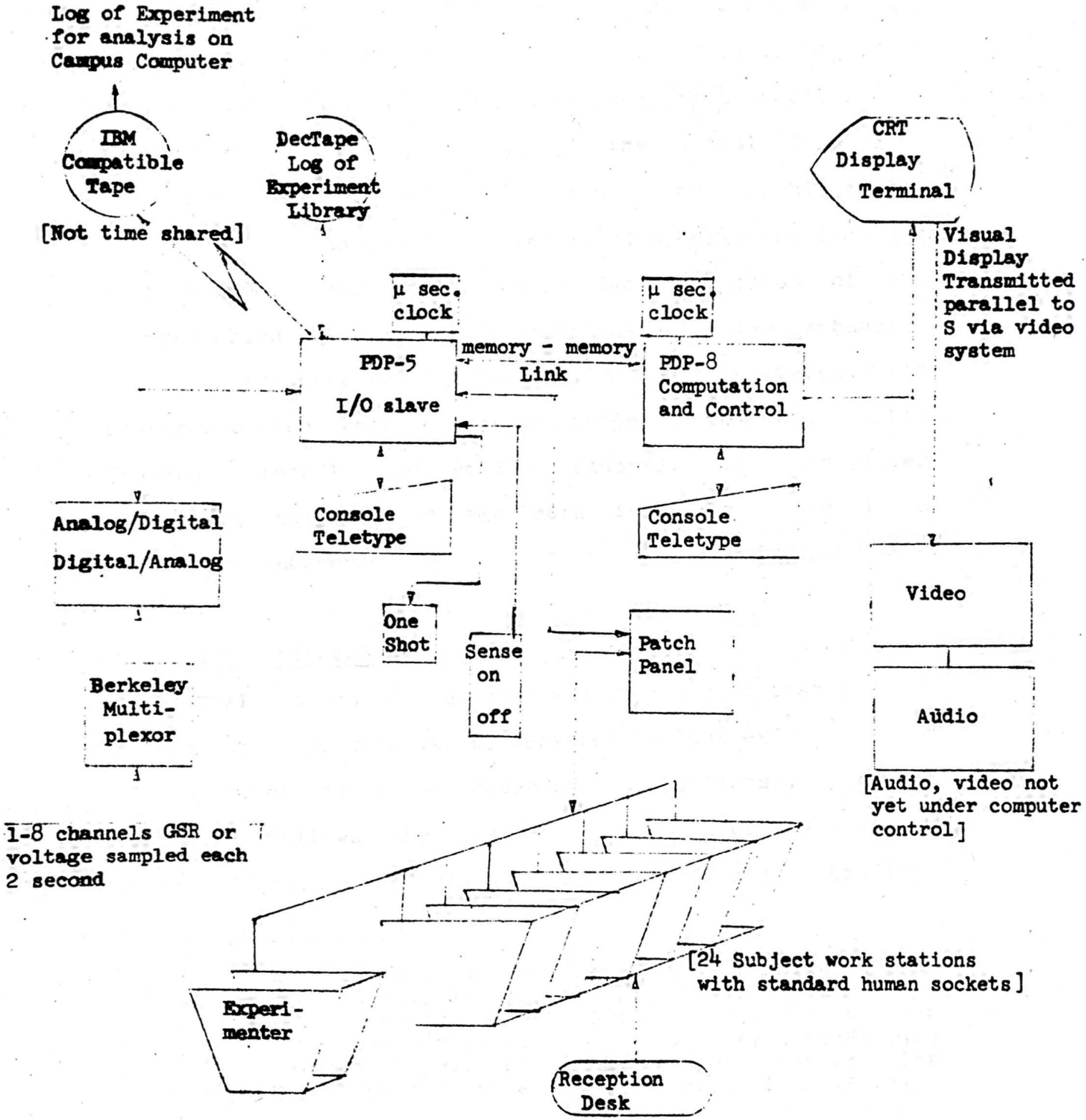


Figure 2 (draft)

Logical Design of Computer Control System

CRMS Lab




(Figure 3 not available)

language ECL/3 (Environmental Control Language, version 3)[3] for the PDP-5/8 system. ECL/3 is designed to implement interactive experiments in a multiple-subject environment. In includes features necessary for the control of parallel processing, subject synchronization, and sophisticated input/output. An example of the ECL/3 programming language is included in Appendix 5.1, which gives a portion of the program which implemented the prototype automated exchange.

In the next two subsections, we describe the specific features of two versions of exchange automation, termed Trading Floor/1 and Trading Floor/2. The objectives underlying their creation are more fully described in a succeeding subsection.

## The Trading Floor/1 System

TF/1 is an operational exchange system that permits trading in three securities, measured in "shares", against a single numeraire asset measured in "dollars". Trading generally follows the rules and procedures of the New York Stock Exchange, as modified slightly for automated trading.

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[3]This language was due largely to the efforts of A. Hoggatt, D. Steingart, J. Schlesinger, and J. Moore; see J. Moore, "ECL/3, The Environmental Control Language of the Management and Behavioral Sciences Laboratory Time-Sharing System", Research Report LR-15 (Berkeley: Center for Research in Management Science, University of California, 1971).

The three securities, called "XXX," "YYY," and "ZZZ," are traded at three distinct "trading posts." The shares of the securities each pay dividends and the numeraire asset, called "cash" (although it may more resemble short-term paper) pays interest. Activity at all the trading posts is communicated to investors via a "ticker-tape" (another computer console) which is in turn relayed to a set of video monitors throughout the physical space.

TF/1 provides a set of accounts for each user; the accounts contain information on the number of shares held in each security and his cash position. No certificates or other evidences of ownership are issued, and the accounts provide the only such records. Clearing is performed automatically on a trade-by-trade basis. Whenever a transaction occurs, the buyer's and seller's accounts are instantly updated.

The TF/1 system was designed with three types of participants in mind: brokers, specialists, and customers. Up to five brokers, three specialists, and twenty-five customers are permitted by TF/1.

The broker operates a computer console to perform the basic functions of making bids, offers, getting account information, etc., usually on behalf of his assigned customers, of which he may have up to five. Brokers may also trade for their own accounts, however. The

specialists' role is modeled after that of the major securities exchanges: the specialist has private access to his book of orders, which he executes on behalf of his client brokers, and in addition he may trade for his own account. Customers access the market only through their assigned brokers, and do not use the computer consoles directly.

As seen by a broker, TF/1 has three modes, the first two of which occur only at the beginning of a trading session. The first of these is the "ID" mode where no further activity may take place until the broker has identified himself to the computer by means of a three-digit identification number. Upon doing so, all the accounts of his customers are automatically identified and the console then enters the "ready" mode. Here the TF/1 system simply waits for the user to select a trading post. A broker selects a trading post by typing the first letter of the security name, i.e. "X", "Y", or "Z", to which the TF/1 system responds by filling out the rest of the command, e.g. "XXX TRADING POST". In this fashion the broker "moves" to a trading post without physically leaving his console. Instead, the transition is a purely logical one.

Once at a trading post, a broker may do any of the following:

He may bid for or offer to sell shares of the security traded at that trading post. Bids and offers are firm commitments (unilateral contracts) to buy or sell specified quantities (stated in multiples of the round lot size) of the security at a specified price (stated in multiples of one-eight of a dollar per share). Bids and offers may enter the market in two ways: for the current auction, in which case they must provide prices at least as good as the current bid/ask prices; or for the specialist's book, whenever the orders' prices fall outside the permitted range. Whenever an order is executed through the specialist's book, the broker involved must split his usual commission with the specialist; if on the other hand, the broker can remain at a trading post and execute his client order himself, he receives the full commission. Commissions are automatically transferred from the customers' cash accounts to the specialists' and brokers' account whenever a transaction occurs.

He may receive a quotation of the bid and ask prices.

He may list all of his personal orders or those of any of his customers.

He may assign his orders to the specialist at the currently selected trading post.

He may leave the currently selected trading post to go to another. However, he may not participate directly in the auction of a trading post that he has left, and will lose all orders at that post which are not given to the specialist.

He may receive a reminder of the current "status" of interest rate, short sale limitations, credit limitations, and commission rates.

The specialist may perform all of the activities of a broker, with the exception that he must remain at his assigned trading post and may not trade in any security other than his own. In addition, a specialist may examine his book of orders, a function denied the brokers.

Customers always trade through their designated brokers. Had a sufficient number of terminals been available in TF/1, all customers would have instead had direct access to the exchange, in effect all would become brokers. Unfortunately, terminals and physical space were limited, and so customers had to compete for the attention of their assigned broker. It is interesting to note that only such competition will rationalize the existence of the specialist in his agency role. That is, if each broker (customer with a terminal) had to attend to only his own needs, there would be no need to give up commissions to the specialist: the broker would simply stay at a trading post until his own orders were executed, and would therefore require no agent at that post.

There appears to be a need for role clarification and learning that could not be entirely satisfied by a written set of instructions. Therefore, such features were built into TF/1 itself. Whenever a user found himself in some kind of input process which he did not comprehend, he had two additional options: Upon depressing the "H" key on his console, the word "HELP" would be written out along with explanatory information describing his alternatives in performing what he wishes to do. Otherwise, a user was provided an escape from his current activity by depressing the "K" key ("KILL") and he will exit from his current input

loop or other difficulty.

The central exchange mechanisms of the TF/1 system perform the following functions:

TF/1 updates all order queues (bid and offer) for all three securities. The priority of orders is modeled after that of the New York Stock Exchange: First-level priority is always assigned by price; the highest bid and the lowest offer always have top priority. If there is a tie in price, second-level priority is assigned is assigned on the basis of the earlier entry time. In the case of simultaneous entry, third-level priority favors orders having larger order quantity sizes. Otherwise, priority, is randomized.

TF/1 matches orders for possible execution. Whenever a buy order and a sell order agree on price, a transaction is possible.

TF/1 executes transactions. If a transaction is possible through agreement of buy and sell order prices, the quantities of the orders involved is compared. If the order sizes are unequal, the smaller order is completely filled, while the larger order's size is reduced by the transaction amount.

TF/1 issues confirmation of executions to the brokers involved in a transaction.

TF/1 automatically updates the accounts of all parties in the transaction, moving shares and cash between buyer and seller, and crediting commissions where due to brokers and specialists.

TF/1 reports the internal state of the market to all investors. New bids and offers and sales may alter the market state. These are transmitted via the video monitors to all market participants, along with the resulting new quotations.

There are several auxiliary functions performed by TF/1. The ticker-tape video monitor link has already been

described. It represents a mechanism for reporting internal market state conditions to all participants. A single computer console was reserved for the ticker-tape.

Another reserved console is the one employed by the market system operator. Upon this console, the market operator may establish such structural aspects as the margin and short-sale limitations, the commission rates, and so on. Also, possible error conditions can be monitored and remedied from this console.

To store external information regarding interest and dividends, TF/1 maintained auxiliary files. The market may thus be "driven" by any sort of external information regarding the three firms: data from a business game, actual historical data, simulated companies and economies, or any other such vehicle. Interest and dividends accrued automatically at the end of fixed real-time periods (whose length is determined by the market operator) for all market participants.

All events occurring in the TF/1 system were monitored and recorded on IBM-compatible magnetic tape. All bids, offers, transactions, and other events were coded, timed as to their occurrence to the second, minute, and hour, and formatted as card-images on the magnetic tape. The purpose of this feature was to allow completely automatic data acquisition for subsequent analysis by off-line computers.

## Trading Floor/2

The CRMS APL-based computer system replaced the CRMS PDP-5/8 system as the primary experimental vehicle in 1974, practically speaking. TF/1 was converted over to the language APL and improved on the basis of usage experience in a major series of experiments. The ability to handle up to about 50 customers and about six or seven brokers was included. Input formats were made more crisp and more extensive data logging was provided. However, the major conceptual change between TF/1 and TF/2 is the integration of the artificial companies into the latter system. Original efforts in TF/1 to control the debt-to-equity ratios of the artificial companies was defeated by the off-line nature of these companies. In TF/2, each company can now, under some circumstances, enter the auctions to float new equity issues at the going market prices. The top-level documentation of TF/1 is attached as an Appendix to the current paper.

## Objectives of the Trading Floor Systems

The creation of the Trading Floor programs spanned three years and required on the order of 4 or 5 man-years of effort. Why was the project deemed important enough to warrant this level of effort? In answering this question, it seems to be appropriate to draw upon an analogy from the

physical sciences: that a complex and expensive machine was built to perform experimentation that heretofore was impossible to perform. Yet there was more than just the experimental possibilities in mind when the project was undertaken.

There were three basic dimensions to the objectives pursued in the creation of the Trading Floor programs. These may be characterized as (1) descriptive, (2) experimental, and (3) educational.

The descriptive aspect arises in the attempt to create a prototype of an automated securities exchange in the image of the New York Stock Exchange (although obviously on a much smaller scale). What happens when the traditional rules of such an exchange are placed in the context of modern computer technology? Although somewhat complicated, the trading rules of the NYSE (e.g. the priorities of orders) turned out to be relatively straightforward to model. The information and communication mechanisms were another matter. For example, at a physical trading post on a real exchange, one can tell exactly which traders are participating in the ongoing auction just by looking around. Or a specialist might size up an approaching broker as to whether or not that broker deals in a large percentage of "market" orders. In an automated exchange there is really no good way to duplicate this sort of face-to-face

interaction. (But alternatively, there would seem to be no demonstrable social benefit advantages accruing from such interaction.) In contrast, certain aspects of information transmission are clearly enhanced in an automated exchange: there may be much less delay in accessing market data on the current quotation, last transaction price and size, etc. More will be said on these differences between automated and non-automated exchanges in the next subsection.

Experimentation goals were also pursued in the creation of the Trading Floor programs. The field of finance has long been constrained in the same fashion that economics has, namely that the empirical base of the subject matter has always been real-world cross-sectional data. The difficulties of controlling irrelevant variables in such an environment is necessarily immense. By contrast, the Trading Floor system offers new horizons in an area we might term experimental finance. Many aspects of portfolio theory, corporate leverage, financial accounting, taxation, securities regulation, underwriting, and others might be capable of being studied in a controlled laboratory environment. Indeed, some questions we cannot now approach due to the restrictive data bases now extant may be answerable in the laboratory.

## II. AUTOMATION OF THE SPECIALIST'S FUNCTION

The specialist operating in a securities exchange has two primary functions. One of these is to act as an agent for his client brokers, aiding them to obtain execution of their limit orders. The other function is that of a dealer, one who profits by standing ready to "make a market" in the security he trades. The first function, that of broker agency, requires little by way of decision-making on the part of specialist. It is instead simply a matter of mechanical information-processing, namely the activation of client orders when market conditions call for same. The second function, dealership activity, is quite a different matter, requiring decision-making skills that presumably take some time to master. The impact of exchange automation falls quite differently upon these two functions in corresponding fashion.

The process of creating TF/1 made it entirely clear (to the author, at least) that the specialist's book itself is straightforward to automate. In fact, the task is complicated only by consideration of the need for possible interaction between the specialist and his book. For example, there was a great deal of discussion amongst the research staff as to whether or not the specialist should be allowed any discretion in executing the orders on his book

that could be so executed. Of course, if the specialist failed to execute orders by crossing or by dealing for his own account in competition with his "public" orders, it left open the possibility that the specialist could thereby "cheat" his clients. Since no SEC or Board of Exchange Governors was to be built into TF/1, it was finally decided that all possible executions that could take place would do so automatically without the assistance of the specialist, but that he would receive his commissions regardless. The only problem that arose with this choice was what to do with stop orders. When the stop price of a stop order is reached, the order often then becomes a "market order" to be executed at the best obtainable price. An activated stop order without a price limit is therefore unlike an other variety of order, inasmuch as the specialist then obtains sole discretion over the execution price of the order. This is unlike the case of an ordinary "market" order that has its auction price set at the discretion of the floor broker acting on behalf of his customer. Handling stop orders in this usual fashion <u>requires</u> the intervention of the specialist. In a fully automated exchange, the alternatives are (1) to refer the stop order back to its original broker (or customer) for execution, (2) prohibit stop orders, or (3) automatically execute stop orders at the "best" obtainable price. Alternative (3) was found to produce some

very dramatic price swings in actual trading.[4] Alternative (1) was rather clumsy to implement. Moreover, it defeats the requirement of rapid execution stop orders are intended to fill. Concensus judgement was that alternative (2) was superior, i.e. stop orders are best eliminated altogether from automated trading. (The rationale for stop orders is that they permit a rapid response to changing market conditions on the part of remote investors; but a fully automated exchange should provide rapid response without such devices, especially a system of symmetric market access.)

Having automated all of the "house-keeping" functions of the specialist, it remained to look to his dealership functions. Here there are two ways to proceed: to either enhance the dealership role or to replace it. The first approach calls for the creation of proper displays, expeditious bidding procedures, and other human factors considerations, with the objective of facilitating the interaction between the specialist, his automated book, and the remainder of the exchange mechanisms. The second approach calls for the elimination of the specialist altogether, replacing his dealership activities with an

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[4]In experimentation, for example, a stock might be trading at around 50 and a stop sell order might be executed at the price 5, since it was momentarily the "best" price.

automated dealer instead.

The first alternative, enhancement of dealership function, was selected in practice. This meant that the specialists interactions with his book were of particular importance. When his book is automatically changing through constant arrivals of new orders and the cancellation of old orders, mechanisms had to be provided to allow the specialist current information on the status of his book. The optimal procedure was judged to be a continual display of the book on a CRT device.[5] Since CRTs were unavailable at the time the Trading Floor programs were constructed, console printouts were employed instead. TF/1 allowed the specialist to list the contents of his book, while TF/2 also noted every change that occurred in the book by a message to the specialist at the time of occurrence.

Although we have not chosen to do so initially, we may nonetheless speculate on the possibilities of automating the specialist's dealership role itself. This suggestion has been made by some authors before,[6] and it has fascinating implications. For example, it appears that we can not

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[5] Cathode Ray Tube. : A graphic display console resembling a television set.

[6] e.g. Mendelson, "The Martin Report and Its Aftermath," The Bell Journal of Economics and MAnagement Science 4, (Spring, 1973), p.265, and Fama, 1970, op.cit.

afford to ignore the game-theoretic features of the marketplace when the specialist's dealership role is automated. Can a dealership algorithm be "gamed", i.e. exploited? Consider an analogue from two-person zero-sum game theory: suppose we set out to develop a robot that will act as one player in such game, the robot being designed to exploit any deviations from a minimax strategy on the part of its human opponent, based on past behavior. It can be shown that there always exist counter-exploitive strategies on the part of the human player which will overcome the algorithm, arguments of bounded rationality and cognitive capacity set aside for the moment. Do there exist exploitive strategies that human traders could use against automated specialists? Is there a concept like the minimax strategy which will prevent exploitation by either party? The answers to these questions are vital if exchange dealership is ever to automated. Future research on this topic is in the planning stage.

# Appendix

## STOCK MARKET SESSION INSTRUCTION MANUAL

In the examples below, the player inputs only what is underlined. Everything else is taken care of by the machine. Please note that you must always depress the space bar to let the machine know when you have finished typing a number or a price. This is indicated below by an underlined blank.

IDENTIFICATION NUMBER: You have been given your own personal identification number. This number must be input at the station you are going to be trading at. When the number is input correctly, you will be told your name, what assignment you have, (Broker, Specialist, Customer), and your account number, (if you are not a Specialist). Once your identification number is input, you need not worry about it again until the end of the game.

***Example***

IDENTIFICATION NUMBER: 118
NAME: PLAYER 118
ASSIGNMENT FOR THIS SESSION: CUSTOMER
ACCOUNT NUMBER FOR THIS SESSION: 2
BEGINNING CASH AND STOCK HOLDINGS:
$50,000.00 10 XXX 10 YYY 10 ZZZ

TRADING OPEN: When trading is open, stock may be bought and sold. Three different stocks are available for this purpose, XXX, YYY, ZZZ. If you are not a Specialist, you will need first to get to the post where the stock you wish to buy or sell is traded.

***Example***

XXX TRADING POST
Now you can make any of the commands listed below for XXX Stock.

YYY TRADING POST
Now you can make any of the commands listed below for YYY Stock.

ZZZ TRADING POST
Now you can make any of the commands listed below for ZZZ Stock.

Specialists can deal only in one stock during the session. Use of the TRADING POST commands will cause an INVALID COMMAND.

Once you are at a TRADING POST you have several options: You can BID, OFFER, LIST your orders, CANCEL an order, or get the QUOTE.

***Example***

BID:
PRICE 15-5 (this represents 15 5/8)
ROUND LOTS 5
ACCOUNT NUMBER 2 (Specialists will not be asked for Account)
CONFIRMED: ORDER NUMBER 1

OFFER:
PRICE 15
ROUND LOTS 1
ACCOUNT NUMBER 1
CONFIRMED: ORDER NUMBER 2

If you want to LIST your active orders now:

LIST ACTIVE ORDERS:

| | NUMBER | ACCOUNT | LOT(S) | PRICE |
|---|---|---|---|---|
| BID | 1 | 2 | 5 | 15-5 |
| OFFER | 2 | 1 | 1 | 16 |

END OF LIST

To Cancel one of the orders:

CANCEL ORDER NUMBER: 2 (Cancels the OFFER we input above)

To find out the best current market BID and OFFER price:

QUOTE: 15-5 NO
Notice that we canceled the only OFFER, thus there is no OFFER price.

To display your accounts at any time:

ACCOUNTS:
ACCOUNT NUMBER 2
$50,000.00 10 XXX 10 YYY 10 ZZZ

Specialists may list the orders on their book:

SPECIALISTS BOOK FOR XXX

NO ORDERS

Currently, there are no orders on the book. (The function of the book will be explained by the experimenter).

TRADING CLOSED: When trading is closed none of the above inputs are valid. The quarter has ended and each person will get a STATEMENT OF ACCOUNTS. Balance Sheets and Income Statements for the Quarter will also be passed out. When all the accounts have been typed out, you will be asked individually, by account number, for a FORECAST of what you think the price and earnings will be

for the three stocks at the end of next quarter.

When all the forecasts are in, trading will open for a new quarter.

SPECIAL KEYS: ERROR, KILL, HELP.

***Example***.

If you are for instance putting in a price:

BID:

PRICE 10-E (What you really wanted was 20-3, but you had typed

PRICE 20-3 already 10-, then hit an E. You will get another chance to type the price in correctly.)

Suppose you are putting in that same price, but what you meant to do was OFFER it not BID it. Hitting an E will only ask for the price again. Hitting a K, however, will get you out of having to put the BID in all together.

If you do not know what to do, or are not sure what is legal, hit an H for HELP.